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LORAN C Field Strength Contours: Contiguous United States

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16. Abstract

This report describes the development of Loran C field strength contour plots for the contiguous United States (CONUS). Various plots were developed which show Loran C field strength based on measured data, predicted data, and measured data augmented by predicted data. Measured data were taken from a data base formerly developed by the Federal Aviation Administration (FAA) Technical Center at the Atlantic City International Airport, NJ. Predicted data were generated by the Canadian Loran C propagation model.

Field strength contour plots of the CONUS are a result of this project. This report concludes that the contours produced are realistic indicators of Loran C field strength for each of the CONUS transmitters. Also included in this report are atmospheric noise contours of the CONUS and Loran C coverage contours of the CONUS.

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EXECUTIVE SUMMARY

The purpose of this project was to produce Loran C field strength contours. The area of interest was the contiguous United States (CONUS). Signal strength contours were developed for each of the 14 Loran C transmitters of the CONUS.

Federal Aviation Administration (FAA) Technical Center Loran C Stability fight test data were the basis for the field strength contours. Figure 1 shows the route along which data were collected during FAA flight tests. The flightpath started in Atlantic City, NJ, and involved six east-west crossings throughout the United States. The purpose of these flights was to evaluate Loran C stability over the CONUS. The flights took place in April/May 1984, July/August 1984, and January/February 1985 (references 1 through 3).

CONUS field strength data collected were adequate to test Loran C stability but not dense enough to plot precise field strength contours for this project. The Canadian Loran C propagation model was used as a tool to augment the field strength data for generating contours. The validity of the data produced by the model is demonstrated in this and in other reports (references 5 and 6).

Also included in this report are CONUS atmospheric noise contours and CONUS Loran C coverage contours.

INTRODUCTION

OBJECTIVE.

The purpose of this project was to produce Loran C field strength contours. The area of interest was the contiguous United States (CONUS). Loran C signal strength contours were developed for each of the 14 Loran C transmitters of the CONUS. Federal Aviation Administration (FAA) Technical Center Loran C Stability flight test data were the basis for the field strength contours.

The data base developed by the FAA Technical Center during flight tests included field strength, signal to noise ratio (phase) (SNR(Ph)), signal to noise ratio (field strength) SNR(FS), envelope to cycle difference (ECD) and atmospheric noise measured along the flightpath. Algorithms developed for plotting field strength were extended so that atmospheric noise contours could be produced. CONUS Loran C coverage contours are also included as a result of this project.

BACKGROUND.

The FAA Technical Center has conducted numerous flight tests concerning Loran C stability. Figure 1 shows the route along which data were collected. The flightpath started in Atlantic City, NJ, and involved six east-west crossings throughout the CONUS.

The flight tests of the CONUS resulted in an excellent Loran C data base of various parameters. The magnitude of the data base allows it to support various projects. Measured data utilized for this project were aircraft position, Loran C field strength, atmospheric noise, and Loran C transmitter identification.

The data collection system sampled and recorded Loran C parameters every 10 seconds. The sampling rate resulted in unique data recorded for approximately each degree of longitude flown along the path. The spacing of the latitude points was controlled by the six east-west crossings which resulted in measured data approximately every 5.0^{o}.

For the purpose of evaluating Loran C stability over the CONUS, the chosen flightpath and data sampling rate were suitable. For this project, the resolution of collected data was inadequate for generating precise Loran C field strength contours.

The collected data had to be supplemented. The Canadian Loran C propagation model was chosen to augment measured field strength data.

The basic software to predict Loran C coverage was obtained from the Canadian Ministry of Transport (MOT). It was rehosted on the FAA Technical Center's VAX 750.

The model software to plot Loran C coverage contours was unique to the Canadian installation. Modification was necessary so that data generated by the Canadian model could be plotted and analyzed on the FAA Technical Center's VAX. The modifications enable the user to predict Loran C coverage graphically and produces coverage data 50 percent faster than the original software. Further enhancements to the model, described in this report, also make possible the output of field strength and atmospheric noise contours.

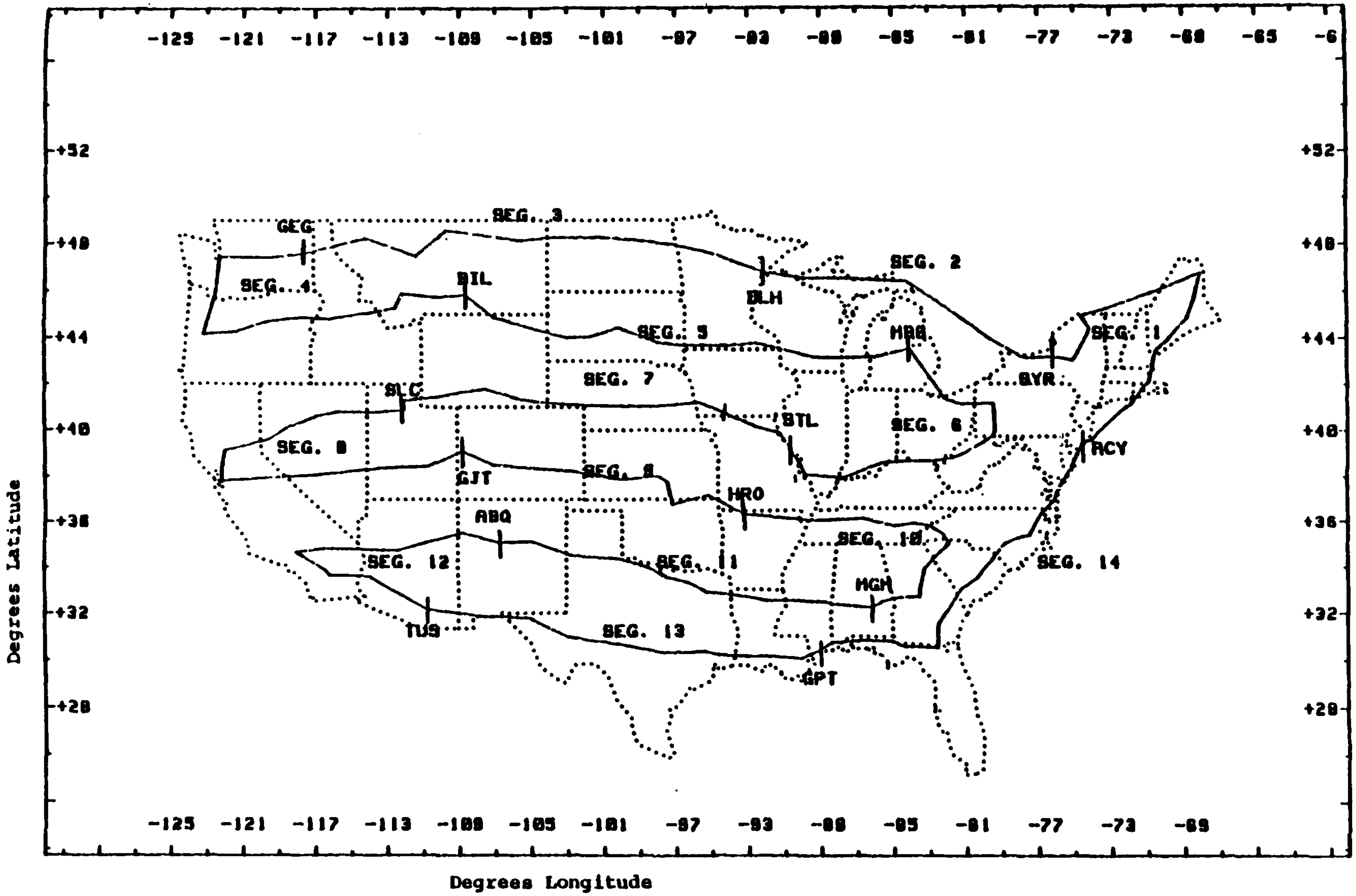


FIGURE 1. LORAN C DATA COLLECTION FLIGHTPATH

The validity of data predicted by the model is demonstrated in this and other reports (references 5 and 6).

DATA EMPLOYED FOR FIELD STRENGTH CONTOURS

FAA TECHNICAL CENTER FLIGHT TEST DATA.

Field strength contours were prepared based on data from the FAA Technical Center's Loran C stability flight tests. The length and width of the flight profile was selected: (1) to encompass large portions of the CONUS, (2) to provide data for Loran C chains over various terrains and conductivity profiles, and (3) to be completed in less than 100 hours of flight time. The purpose of the stability flight tests was to investigate seasonal time difference variations in the Loran C grid over the CONUS and the resulting position errors as they pertain to FAA Advisory Circular 90-45A. The flights took place in April/May 1984, July/August 1984, and January/February 1985 (references 1 through 3).

All data parameters were collected using a Norden militarized PDP 11/34 minicomputer with a 9-track tape recorder (reference 1). The Aircraft Tracking and Data System (ATADS) was used to generate a reference aircraft position based on multiple distance measurement equipment (DME) ranges from several ground stations.

ATADS consists of a modified airborne DME interrogator unit (cycle tracker) and a microprocessor unit. Station channeling, station acquisition, and range tracking were controlled by the microprocessor. The normal sequencing rate of the cycle/tracker was 10 stations per second. The ATADS was configured to function in a free scan mode, whereby the stations were selected on a first-come-first served basis using sequential scanning.

The following production model Loran C receivers were used for the test: Teledyne TDL-711, Micrologic ML-4000, Texas Instruments TI-9100, and two Advanced Navigation ANI-7000 units. All receivers were operated in the wide open mode, i.e., automatic station selection, except the TDL-711 which required manual entry of the chain and triad. The data collection system sampled and recorded Loran C parameters every 10 seconds.

Data collected along the flightpath, important to this project, included latitude/longitude position of the receiver, Loran C transmitter identification, received Loran C field strength, and atmospheric noise.

FLIGHT TEST DATA AUGMENTED BY MODEL DATA.

The object of this project was to produce field strength contours for each of the Loran C transmitters listed in table 1. Data collected during FAA Technical Center's Loran C flight tests would be the basis for generating the contours.

TABLE 1. LORAN C TRANSMITTERS -- CONUS

Station	Latitude	Longitude	Radiated Power (kW)
Nantucket	N 41° 15'11.9''	W 69° 58'39.09''	400.0
Caribou	N 46° 48'27.1''	W 67° 55'37.71''	600.0
Seneca	N 42° 42'50.6''	W 76° 49'33.86''	800.0
Baudette	N 48° 36'49.8''	W 94° 33'18.47''	800.0
George	N 47° 03'48.0''	W 119° 44'39.53''	1200.0
Dana	N 39° 51'07.5''	W 87° 29'12.14''	400.0
Fallon	N 39° 33'06.6''	W 118° 49'56.37''	400.0
Middletown	N 38° 46'57.0''	W 122° 29'44.53''	400.0
Searchlight	N 35° 19'18.2''	W 114° 48'17.44''	540.0
Malone	N 30° 59'38.7''	W 85° 10'09.31''	800.0
Grangeville	N 30° 43'33.0''	W 90° 49'43.60''	800.0
Carolina Beach	N 34° 03'46.1''	W 77° 54'46.65''	700.0
Raymondville	N 26° 31'55.0''	W 97° 50'00.01''	400.0
Jupiter	N 27° 01'58.4''	W 80° 06'53.04''	400.0

The data collection system sampled and recorded Loran C parameters every 10 seconds. The sampling rate resulted in unique data recorded for approximately each degree of longitude flown along the path. The spacing of latitude points was controlled by the six east-west crossings which resulted in measured data approximately every 5.0°. For this project, the resolution of collected data corresponding to longitude was adequate. The resolution of measured data corresponding to latitude was unsatisfactory.

Figure 2 is a plot of field strength measured along the flightpath. The indicated transmitter is centered in the plot. The data were collected during summer Loran C stability flight tests. Field strength units are in decibels per microvolt per meter (dB/μV/m). Numbers in the plot are scaled according to the following formula:

field strength / 10; + / - 1.0 dB/μV/m

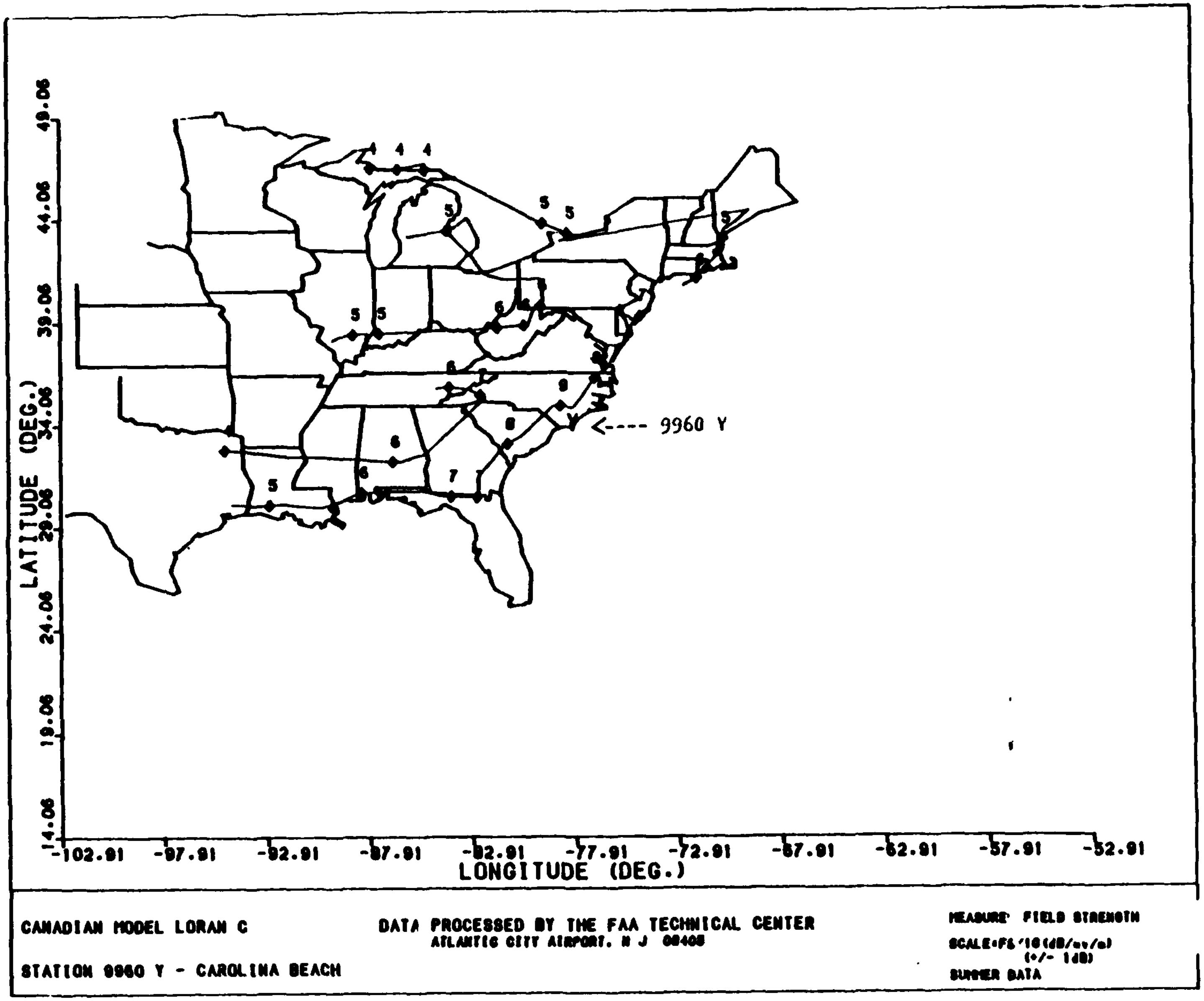


FIGURE 2. MEASURED FIELD STRENGTH

It was evident from the plot that contours produced from measured data alone would not be possible. The density of the collected data resulted in poor vertical resolution. Contours which would result from connecting field strengths of the same value would not be precise.

Appendix A contains a complete set of measured field strength plots. Each plot shows the flight measured field strength in the vicinity of the indicated Loran C transmitter.

The CONUS field strength data collected were not dense enough to produce precise Loran C field strength contours. Former attempts to produce plots (reference 4) based on measured field strength data required "artistic" overlays. Figure 3 is a plot from the above noted document which shows the measured field strength along the flightpath of the indicated station. Dashed lines were drawn to connect points with constant field strength. The dashed line contours indicate field strength as a function of distance only. In reality, conductivity of the path must also be considered.

A scientific technique was needed to "fill in the gaps" left by the flightpath during data collection. The precise method for producing signal strength contours would consist of an algorithm which calculates field strength based on transmitter radiated power, transmitter-receiver range, and path conductivity. The Canadian Loran C propagation model was chosen as the tool to scientifically enhance the measured field strength data for plots.

The validity of the data produced by the model is demonstrated in this and in other reports. The Canadian model has been extensively analyzed and improved by the FAA Technical Center (references 5 and 6). It has been shown to have valid algorithms for predicting Loran C coverage.

The Canadian Loran C propagation model was judged to be a valuable tool for this project. One reason was its ability to predict Loran C coverage contours which compare favorably with those of the United States Coast Guard (USCG). It predicts coverage contours based on calculating probable fix accuracy of two times distance root mean square (2DRMS) and signal to noise ratio (SNR). Loran C coverage contours predicted by the model appear in appendix E.

The Canadian model was also valued for this project because unique data for atmospheric noise and conductivity is returned for each 0.5° latitude and longitude evaluated. The high resolution data and valid algorithms employed by the model result in a realistic field strength calculation for a simulated transmitter-receiver path. Other Loran C prediction models may use mean values for cells greater than this resolution. An example would be the MITRE airport screening model for nonprecision approaches using Loran C navigation systems. The MITRE model (PC version) divides the CONUS into 60 cells for both noise and conductivity values (reference 7). In contrast, the Canadian model uses approximately 6000 cells of unique noise and conductivity data for the CONUS. The high resolution conductivity map of the Canadian software predicts a field strength which more accurately reflects the conditions along the signal path.

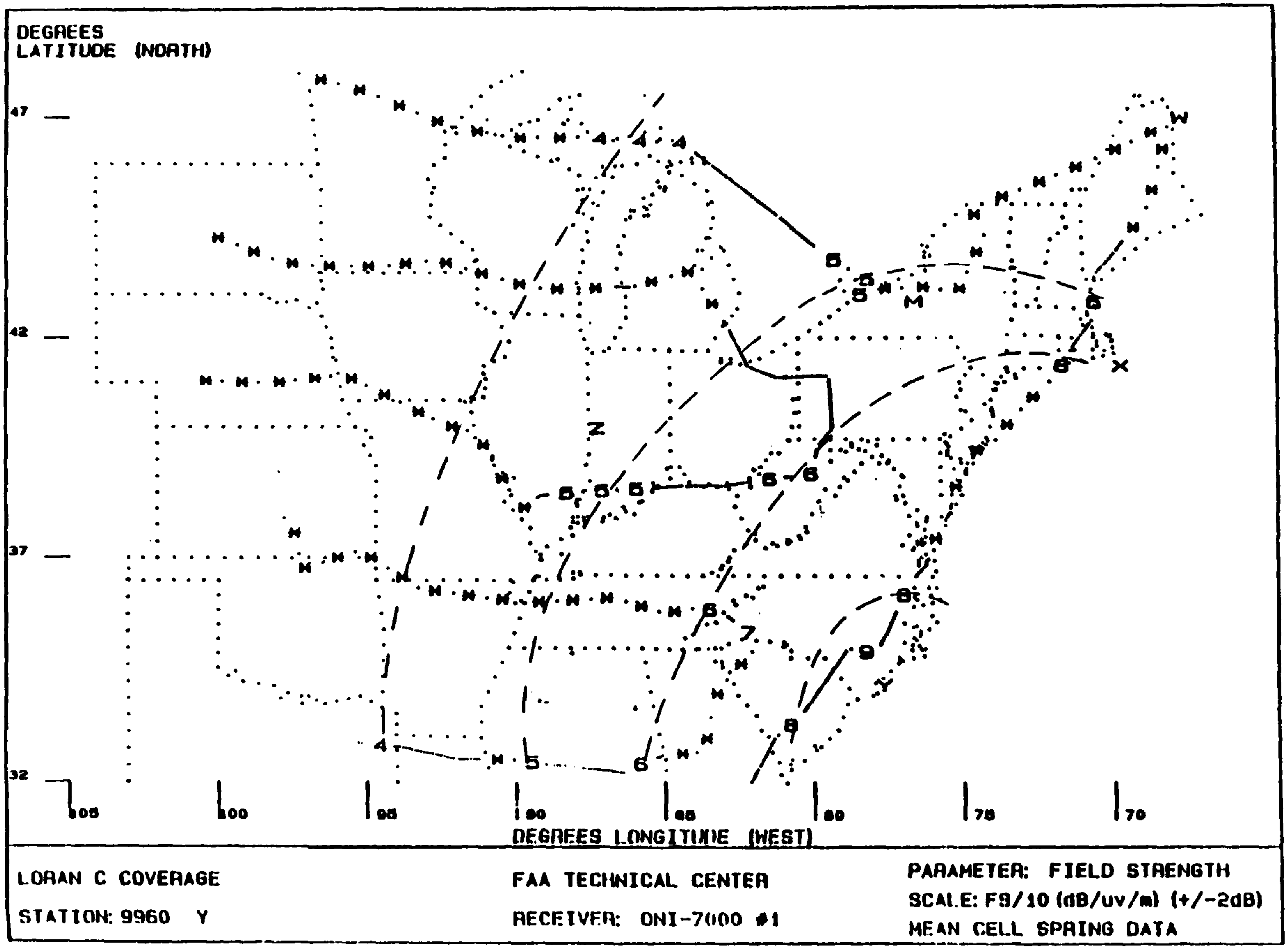


FIGURE 3. MEASURED FIELD STRENGTH OVERLAID WITH ARTISTIC CONTOUR

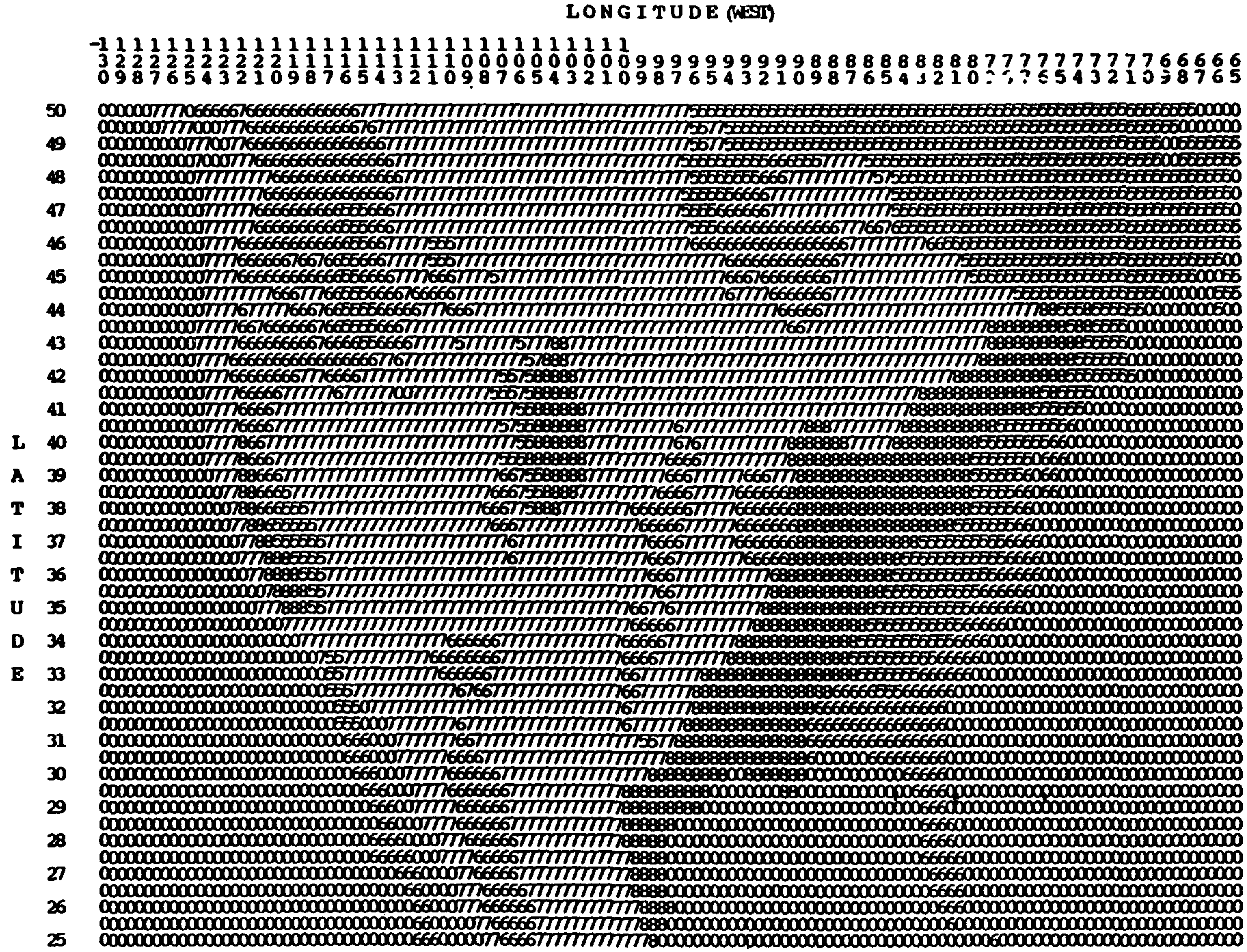
PREDICTED LORAN C FIELD STRENGTH. Received signal strength is a function of transmitter radiated power, distance traveled, and path conductivity. The signal attenuates least over seawater and greatest over glacial ice. Because the propagation path will encounter different and changing conductivities, a special c[illegible]ion algorithm is employed. The Canadian software makes use of Millington's method to evaluate the expected value of received signal field strength over a mixed path.

Millington's method assumes that the field strength over a mixed path is the geometric mean of the initial field and the field computed when the transmitter and receiver are interchanged (reference 8). The Canadian model determines the number and type of electrically homogeneous segments of conductivity over which the signal propagates. Minimum segment path length is 2 nautical miles (nmi) with 10 possible conductivity values. This conductivity value along with the proper field strength curve from the International Radio Consultative Committee (CCIR) groundwave propagation graph renders a unique field intensity for a particular distance.

FIELD STRENGTH VS. RANGE AND CONDUCTIVITY. The conductivity values appearing on the MORGAN conductivity map were not generated specifically for Loran frequencies. Differences between the MORGAN values and real-world values are expected to exist but should generally be small. The Canadian model uses conductivity values based on the MORGAN conductivity map. A conductivity value is provided for every 0.5° of latitude and longitude. The model was packaged with a conductivity data base which encompasses the entire globe. Figure 4 shows conductivity values used throughout the CONUS. The high resolution of this conductivity map results in predictions for field strength which are sensitive to varying conductivities.

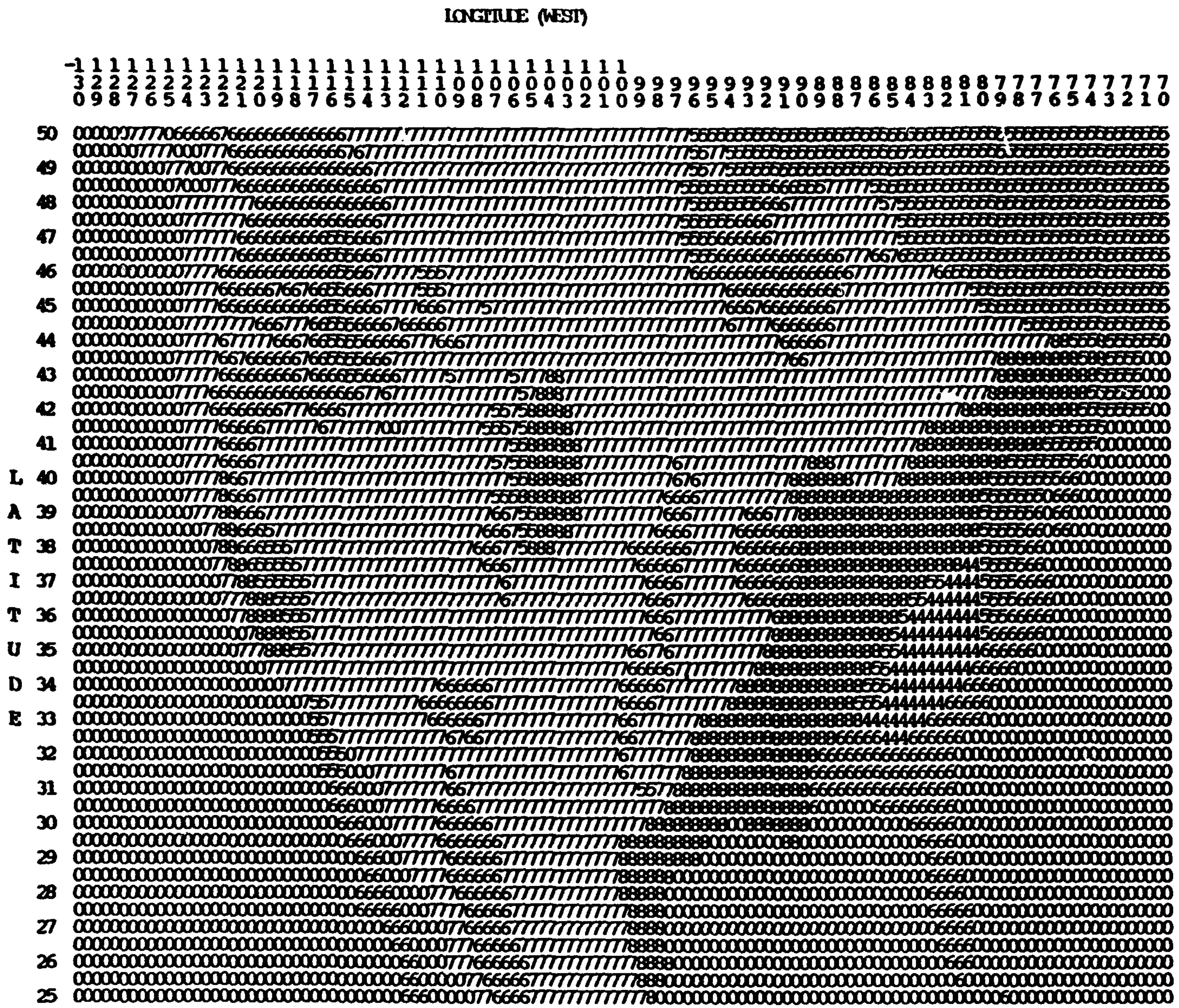
Figure 4 represents the model employed values which have been revised by the FAA Technical Center. The CONUS portion of the original conductivity data base delivered with the Canadian model is shown in figure 5. Figure 5 shows poor conductivity values for the Southeast United States (U.S.) from north latitude 32.5° to 37.5°, west longitude 80.0° to 86.5°. The original value of .32 millimho per meter (mmho/m) (map code value "4") for this area was far below those published by the USCG. The USCG published conductivities (reference 8) for that region range from 1.0 to 4.0 mmho/m per meter (figure 6). The original Canadian software predicted conductivity for that area to be at least three times more severe than the USCG. Predicted field strength was therefore lower than expected. For this reason, the conductivity data base was altered to correspond more closely with the values published by the USCG. Figure 4 shows the revised values to be 1.0 mmho/m per meter throughout the indicated region.

The software calculates field strength values based on CCIR groundwave propagation curves for 100 kilohertz (kHz). Figure 7 is an overlay of the Canadian model's propagation curves (plots marked with symbols) versus the USCG curves published in the Wild Goose Association (WGA) publication No. 1/1976 (background bold lines). The Canadian software includes some groundwave field intensity curves which have no exact correspondence with those published by the USCG. Table 2 shows a list of conductivities for which the Canadian model provides field strength propagation curves. It also shows comparable conductivities for which the USCG provides propagation curves. Conductivities provided in the model for which there are no exact correspondence are .010 mmho/m, .032 mmho/m, .320 mmho/m, 3.2 mmho/m, 32.0 mmho/m, 100.0 mmho/m and 4.0 mho/m.



CONVERSION TABLE: 0 = 4000 mmho/m 8 = 32 mmho/m 6 = 3.2 mmho/m 4 = .32 mmho/m 2 = .032 mmho/m
9 = 100 mmho/m 7 = 10 mmho/m 5 = 1.0 mmho/m 3 = .10 mmho/m 1 = .010 mmho/m

FIGURE 4. REVISED MODEL CONDUCTIVITY MAP -- UNITED STATES



CONVERSION TABLE:

0 = 4000 mmho/m	8 = 32 mmho/m	6 = 3.2 mmho/m	4 = .32 mmho/m	2 = .032 mmho/m
9 = 100 mmho/m	7 = 10 mmho/m	5 = 1.0 mmho/m	3 = .10 mmho/m	1 = .010 mmho/

FIGURE 5. ORIGINAL MODEL CONDUCTIVITY MAP -- UNITED STATES

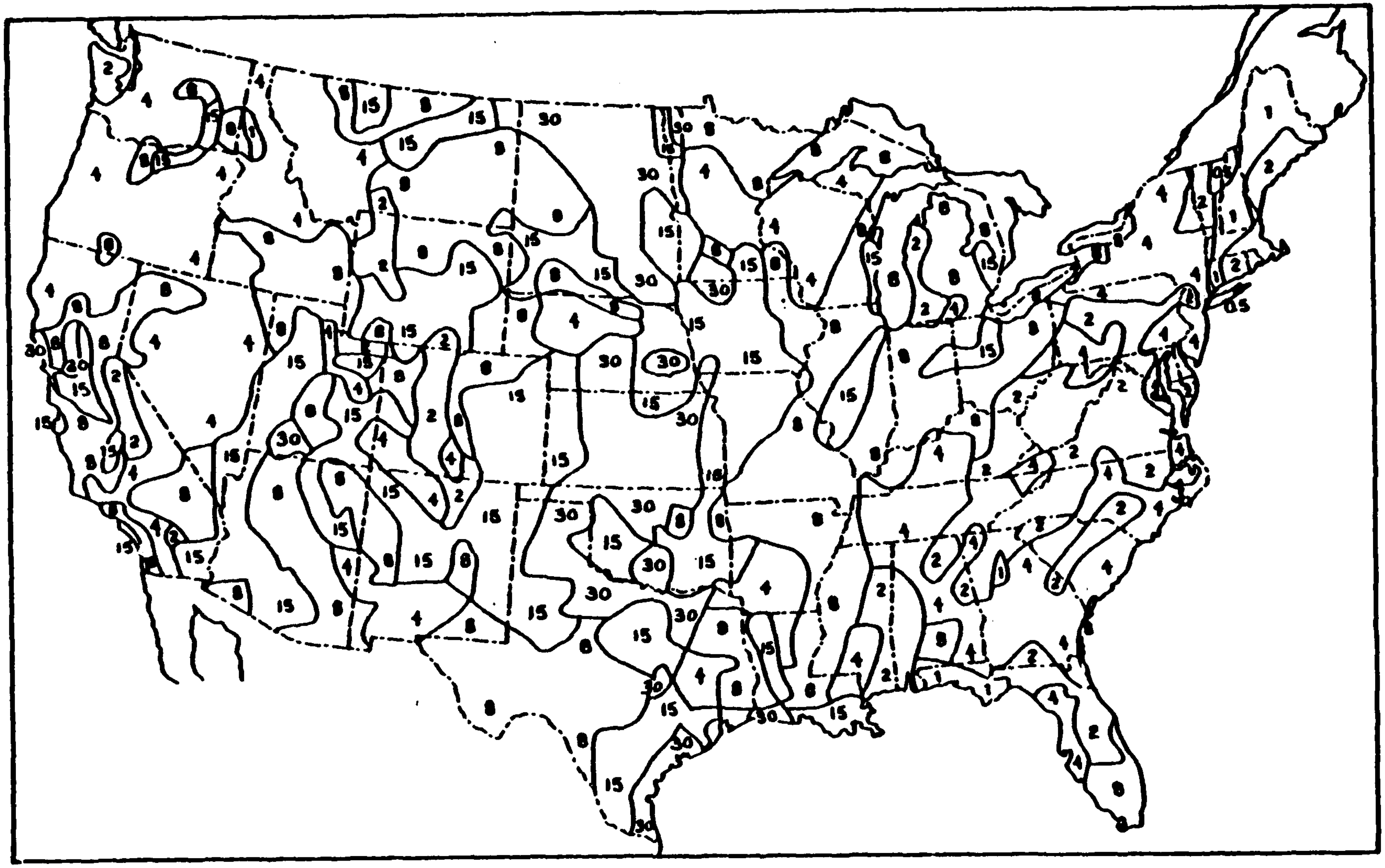


FIGURE 6. U.S. COAST GUARD CONDUCTIVITY MAP

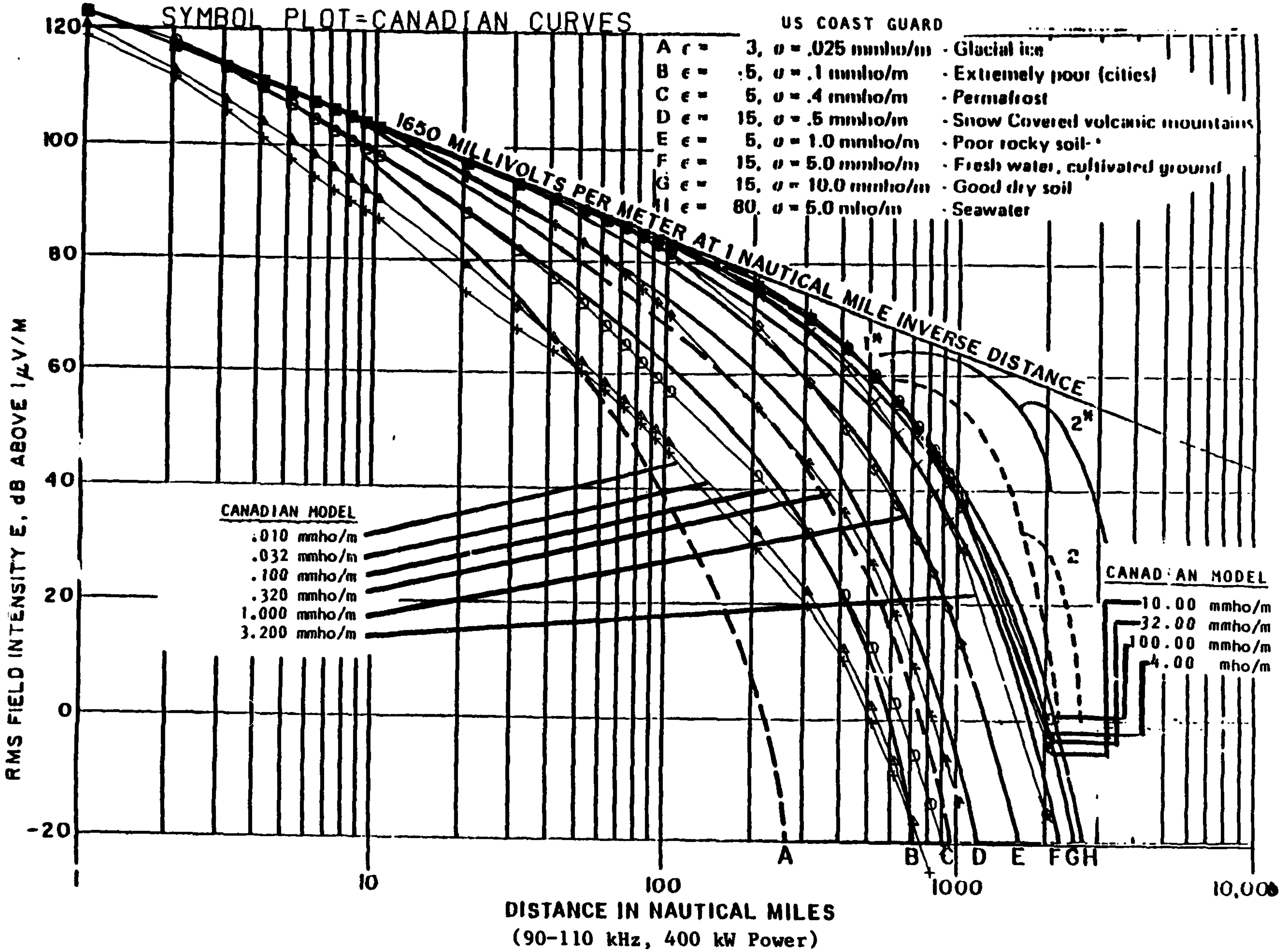


FIGURE 7. GROUNDWAVE FIELD INTENSITY

TABLE 2. CONDUCTIVITY VALUES

Canadian Model	US Coast Guard
.010 mmho per meter	- - - - - - - - -
.032 mmho per meter	.025 mmho per meter
.100 mmho per meter	.100 mmho per meter
.320 mmho per meter	.400 mmho per meter
- - - - - - - - - -	.500 mmho per meter
1.000 mmho per meter	1.000 mmho per meter
3.200 mmho per meter	5.000 mmho per meter
10.000 mmho per meter	10.000 mmho per meter
32.000 mmho per meter	- - - - - - - - - - - -
100.000 mmho per meter	- - - - - - - - - - - -
4.000 mho per meter	5.000 mho per meter

The propagation curves of importance are those which correspond with the USCG's curves labeled E, F, G, and H in figure 7. These curves correspond to the conductivities which prevail throughout the CONUS. The conductivity values for USCG curves E and G have an exact correspondence in the Canadian software. The conductivity values for USCG curves labelled F and G have approximate counterparts in the Canadian software. The USCG value of 5.0 mmho/m closely corresponds to the Canadian model value of 3.2 mmho/m and USCG value of 5.0 mho/m closely corresponds to Canadian model value of 4.0 mho/m.

For distances less than 1000 nmi, figure 7 shows values returned by the Canadian model for a given conductivity appear within 2 dB/μV/m of those published by the USCG. There are propagation curves which show a greater degree of incompatibility with the USCG but they are not employed in the region of concern. For that reason, revision of the model in the area of the propagation curves was not necessary.

LORAN C TRANSMITTER RADIATED POWER DATA.

Most of the CONUS Loran C transmitters have been upgraded to either low power or high power solid state transmission. Low power transmitters can radiate 400 kilowatts (kW) peak power. High power solid state transmitters can radiate a peak power of 800 kW. The actual radiated power may vary from the maximum. As an example, lower than maximum power may result because of antenna configuration.

The power ratings listed in table 1 are the most recent values either "measured" or "published" by the USCG. Where actual measured values were different from values which the transmitter was designed to operate at, the lower of the two values were used for modeling purposes. This would result in a "worst case" prediction.

Some of the Loran C transmitters were upgraded after the Loran C stability flight tests. These transmitters, along with former power ratings, are shown in table 3.

TABLE 3. UPGRADED LORAN C TRANSMITTERS - CONUS

Station	Former Power (kW)	Current Power (kW)
Nantucket	275.0	400.0
Caribou	350.0	600.0
Baudette	500.0	800.0
Carolina Beach	550.0	700.0
Jupiter	275.0	400.0

Plots in appendix B and the next section show a comparison between model predicted field strength contours and flight measured field strengths. Because the flights took place before the transmitters in table 3 were upgraded, parameters were set in the model to reflect the former power ratings for comparison plots. The Canadian model predicted field strength contours, in which comparisons were not made, reflect only the current power ratings. These plots appear in appendix C.

MEASURED FIELD STRENGTH DATA COMPARED WITH PREDICTED CONTOURS.

Figure 8 is an overlay of flight measured field strength data (figure 3) and model predicted data. The Loran station used in this analysis is dual-rated Carolina Beach. Carolina Beach is on the Northeast U.S. Loran C chain 9960Y and on the Southeast U.S. chain 7980Z. Radiated power for this station at flight test time was 550 kW. The comparison plot in figure 8 reflects a 550 kW transmission. Since the flight test, Carolina Beach has been upgraded to 700 kW. Plots in appendix C reflect the updated power rating.

Data reduction techniques and scaling used for the flight data in the plot are explained in appendix A. Algorithms used to produce the model predicted contours are explained in appendix C. Field strength units are in dB/μV/m. Numbers in the plot are scaled according to the following formula:

field strength / 10; + / - 1.0 dB/μV/m.

It is evident from figure 8 that the Canadian software does a good job predicting Loran C field strength when compared with measured data. Predicted and measured data usually correspond. Predicted data which does not agree appears within 2 to 5 dB/μV/m of flight measured data.

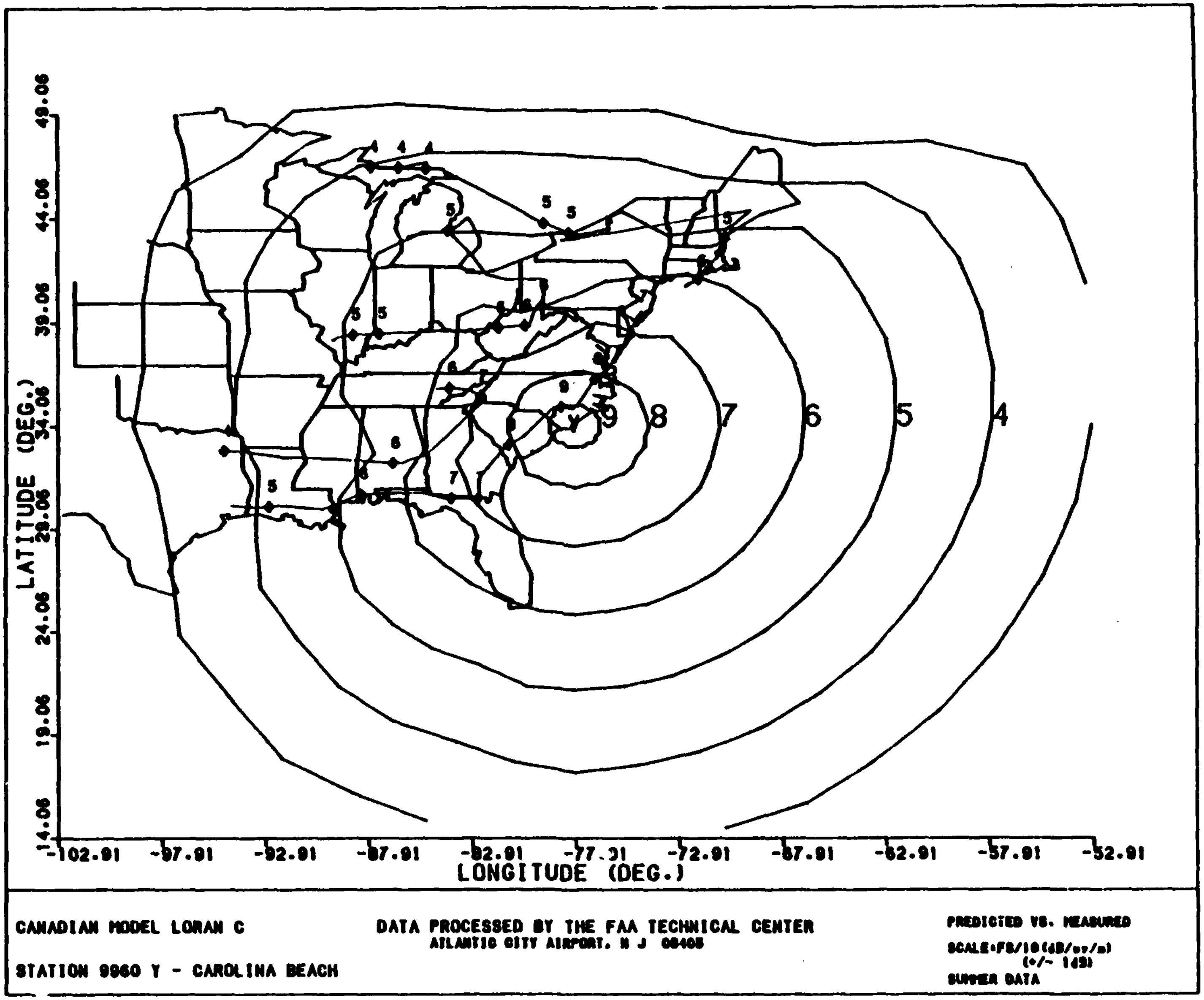


FIGURE 8. MEASURED FIELD STRENGTH OVERLAID WITH PREDICTED CONTOUR

In figure 8, the visible difference that exists between measured and predicted field strength data may be less than it appears. Where a difference exists between predicted and measured field strength values, the model was typically 2 to 5 dB/µV/m higher than the measured values. In part, some of this difference can be attributed to data collection techniques. The Alaska Loran C P--h- Test Results technical note (reference 9) indicated a need for an antenna calibration value when measuring field strength in order to obtain a true field strength value. The calibration value is receiver dependent and is computed for distances of 10 to 50 nmi from a transmitter.

According to the technical note, the average antenna calibration value for the receiver used was 2 dB/µV/m. The antenna calibration values mu-- be added to measured field strength to obtain true field strength values. Because of this phenomenon one would expect model predictions for field strength to be somewhat higher than measured field strength. Adding an antenna calibration value to the measured values would bring the model values and flight test values closer together.

It is evident from the plot in figure 8 that the model usually does predict field strength data greater than what was measured along the flight. An exception is in the south and southeast area. Here, the model predicts a field strength less than expected. This occurs because of the poor conductivity values employed for this region by the software.

A full series of comparison plots for all the transmitters listed in table 1 appear in appendix B.

FIELD STRENGTH CONTOURS

The Canadian Loran C propagation model was enhanced by the FAA Technical Center so that predicted field strength contours could be output based on receiver distance from a transmitter. Model algorithms used to produce the plots are explained in appendix C.

Figure 9 is an example of field strength contours produced by using the Canadian model as a tool. Each contour shows a field strength which is a multiple of 10 dB/µV/m, +/- 1 dB/µV/m for the indicated station.

With the model revisions indicated in this document, realistic contours of the CONUS are predicted. Contours were generated for each of the 14 Loran C transmitters listed in table 1. The full set of plots are shown in appendix C. The contours are based on the current radiated transmitter powers listed in table 1.

The field strength contours of appendix C, produced from model predicted data, show continuity. The plots of appendix A based on the flight measured data lack this continuity. Precise contours result when high resolution data are utilized. Although the contours are predicted, the last section shows them to be reasonable. The model error inherent in figure 9 and appendix C plots could be overlooked for certain applications.

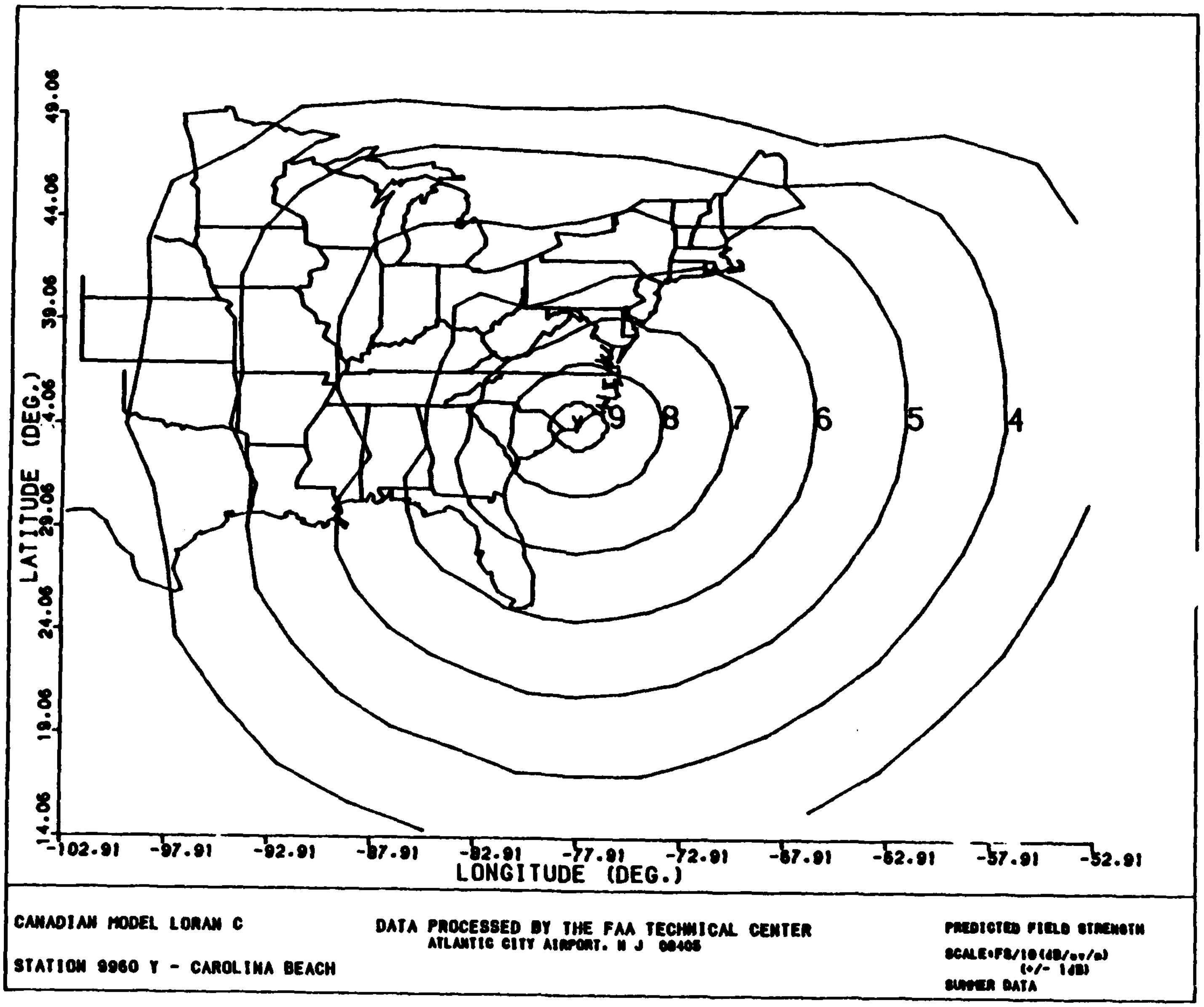


FIGURE 9. PREDICTED FIELD STRENGTH CONTOUR

Where application is more demanding, the plots of appendix A should be employed. Note that the data reduction employed for those plots do not reflect the antenna calibration value discussed in the last section. The plots of appendix A show field strength data "as measured."

CONCLUSIONS

The object of this project was to produce field strength contours for each of the Loran C transmitters listed in table 1. Data collected during Federal Aviation Administration (FAA) Technical Center's Loran C flight tests was the basis for generating the contours.

There were two problems associated with this project. First, precise field strength contours could not be generated from flight tests alone because collected data resolution was poor. It was also shown that data collection techniques for field strength measurement result in raw data which must be adjusted by adding an antenna calibration value. The plots of appendix A do not reflect this adjustment.

Secondly, contours produced from predicted data have a certain margin of modeling error. Overall, the Canadian model software was shown to predict realistic field strength values, but lower than expected values were predicted through part of the southern United States. Poor conductivities values employed for that region caused the problem.

True field strength contours could therefore not be produced based on current existing data, whether measured or predicted.

Realistic field strength contours have resulted from this project. The plots in appendix C are reasonable, based on a comparison of measured and predicted field strength data. Correlation between measured and predicted data show them to be mutually supportive. It is, therefore, reasonable to accept each of the plots in appendix C as a practical indicator of Loran C field strength.

RECOMMENDATIONS

The Canadian Loran C propagation model has been shown to be a valuable prediction tool. Coverage and field strength contours predicted by the model are reasonable. It is, therefore, recommended that the field strength contour plots of appendix C be accepted as good indicators of CONUS Loran C field strength.

One area of concern is the Canadian model's conductivity map employed for the United States (U.S.). This conductivity map does not agree favorably with the U.S. Coast Guard (USCG) in some areas of the CONUS. The model could be enhanced significantly if a map based on true CONUS conductivity was employed.

Synetics Corporation of Reading, Massachusetts, is currently working on a project for the USCG titled "Development of a Loran C Signal Strength Model." Part of the project involves developing seasonal conductivity maps of the CONUS based on the FAA Technical Center's Loran C stability flight tests data. Synetics' conductivity map should more accurately define CONUS conductivity. Predicted data from the Canadian model may be more accurate if the software utilized Synetics' conductivity map. It is recommended that Synetics' conductivity map be tested in the Canadian

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APPENDIX A

MEASURED FIELD STRENGTH DATA PLOTS

LIST OF ILLUSTRATIONS

Field strength plots in this appendix are from the Federal Aviation Administration (FAA) Technical Center's Loran C summer stability flight tests. The length and width of the flight profile was selected: (1) to encompass large portions of the CONUS, (2) to provide data for Loran C chains over various terrains and conductivity profiles, and (3) to be completed in less than 100 hours of flight time. The purpose of the stability flight tests was to investigate seasonal time difference variations in the Loran C grid over the CONUS and their resulting position errors as they pertain to FAA Advisory Circular 90-45A. The flight took place in April/May 1984 (reference 1).

All data parameters were collected using a Norden militarized PDP 11/34 minicomputer with a nine-track tape recorder. The Aircraft Tracking and Data System (ATADS) was used to generate a reference aircraft position based on multiple distance measurement equipment (DME) ranges from several ground stations.

The data collection system sampled and recorded Loran C parameters every 10 seconds. The sampling rate resulted in unique data recorded for approximately each 1.0° of longitude flown along the path. Corresponding to latitude, the 6 east-west crossings resulted in measured data approximately every 5.0°.

The plots of this appendix show the field strength measured along the flightpath. The indicated transmitter is centered in the plot. Field strength units are in decibels per microvolt per meter (dB/μV/m). Numbers in the plot are scaled according to the following formula:

field strength / 10;   + / - 1.0 dB/μV/m

The plots of this appendix represent field strength data as it was recorded in flight. True field strength may be different from the values seen in the plots. The difference can be attributed to data collection techniques. The Alaska Loran C Probe Test Results technical note (reference 9) indicated a need for an antenna calibration value when measuring field strength in order to obtain a true field strength value. The calibration value is receiver dependent and is computed for distances of 10 to 50 nautical miles (nmi) from a transmitter.

According to the technical note, the average antenna calibration value for the receiver used was 2 dB/μV/m. The antenna calibration values must be added to measured field strength to obtain true field strength values.

Plots in this appendix are grouped by Loran C chain. Some stations are dual rated, that is they are configured and function in two different chains. Radiated power remains the same, therefore plots of stations which are dual rated appear once in the appendix. Figures A-1 through A-5 of this appendix are measured field strength plots of the Northeast 9960 Loran C transmitters. Data are plotted along the flightpath for each of the indicated stations. Figures A-6 through A-9 are measured field strength plots along the flightpath for the Southeast 7980 chain. Figure A-10 is data for the Great Lakes station 8970 Y. Field strength data for stations of the West Coast chain are shown in figures A-11 through A-14.

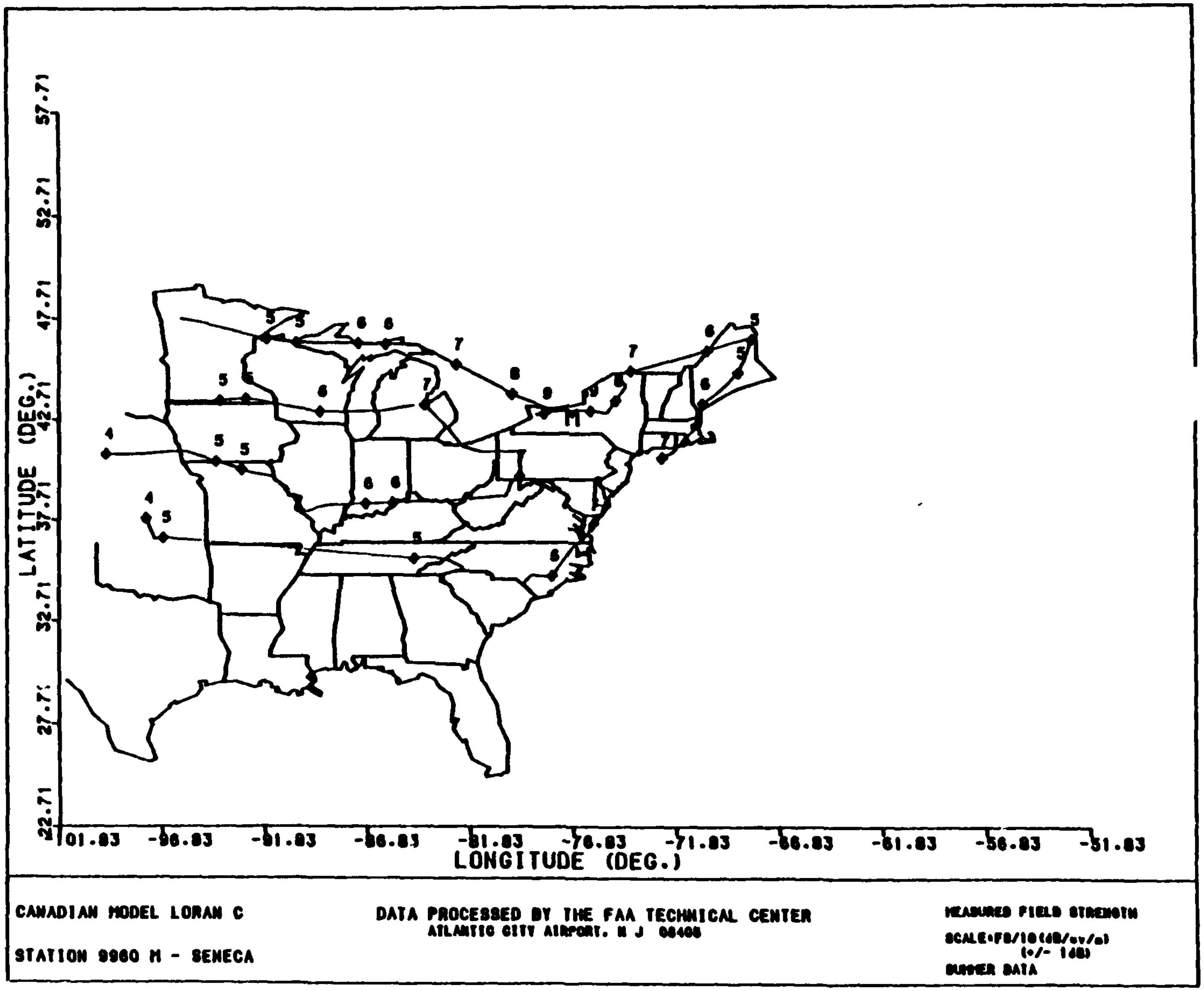


FIGURE A-1. MEASURED FIELD STRENGTH DATA, SENECA STATION 9960 M

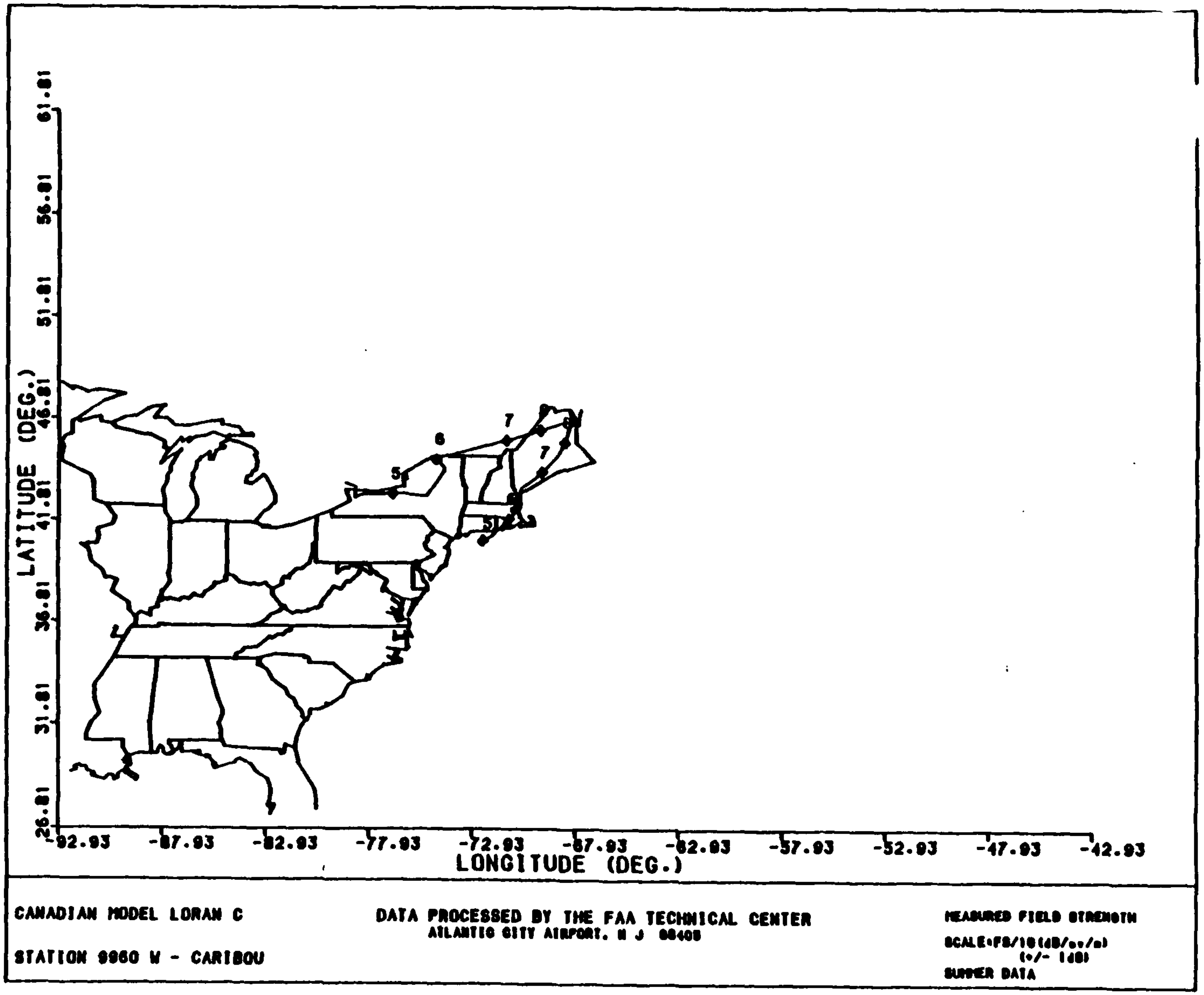


FIGURE A-2. MEASURED FIELD STRENGTH DATA, CARIBOU STATION 9960 W

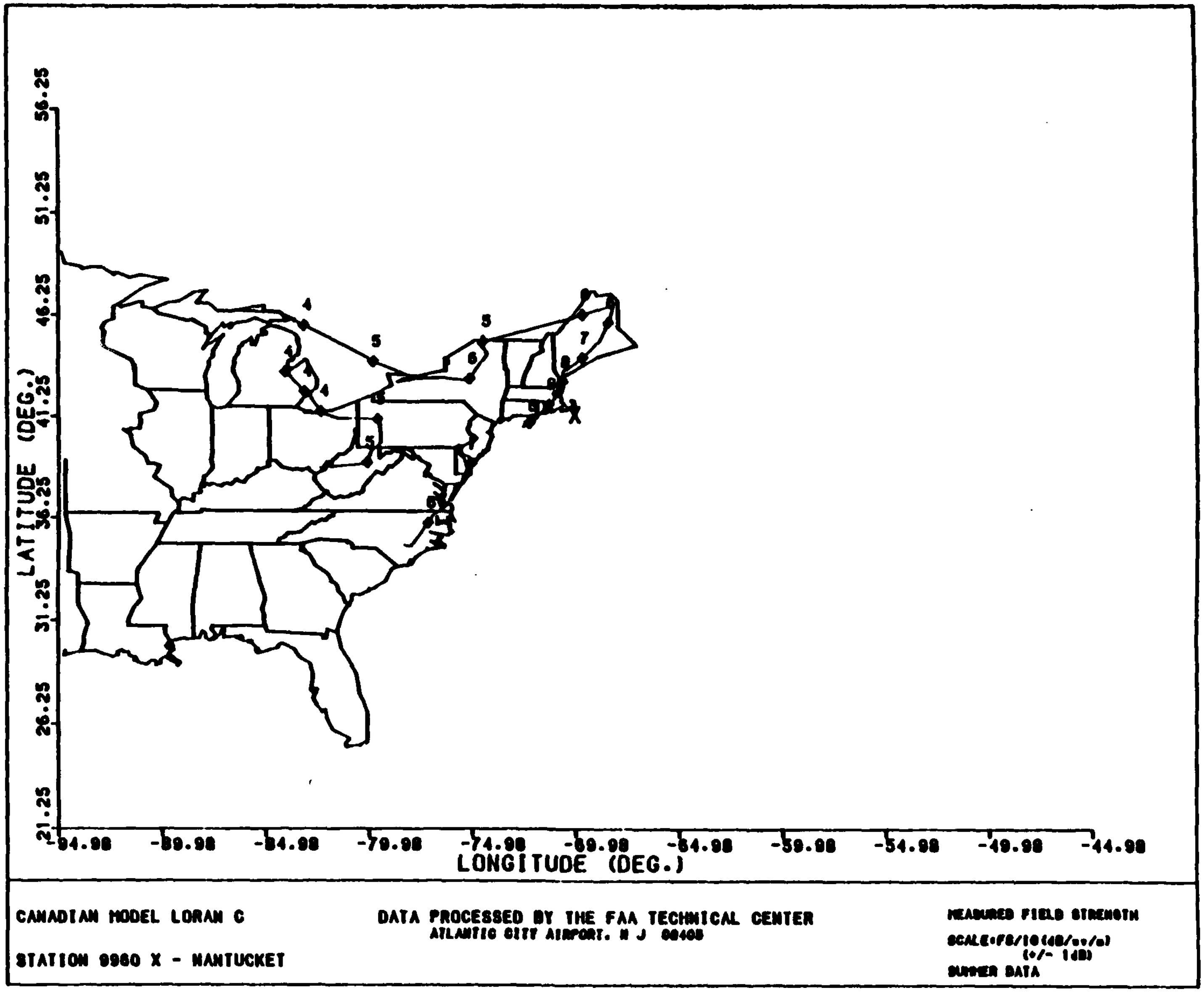


FIGURE A-3. MEASURED FIELD STRENGTH DATA, NANTUCKET STATION 9960 X

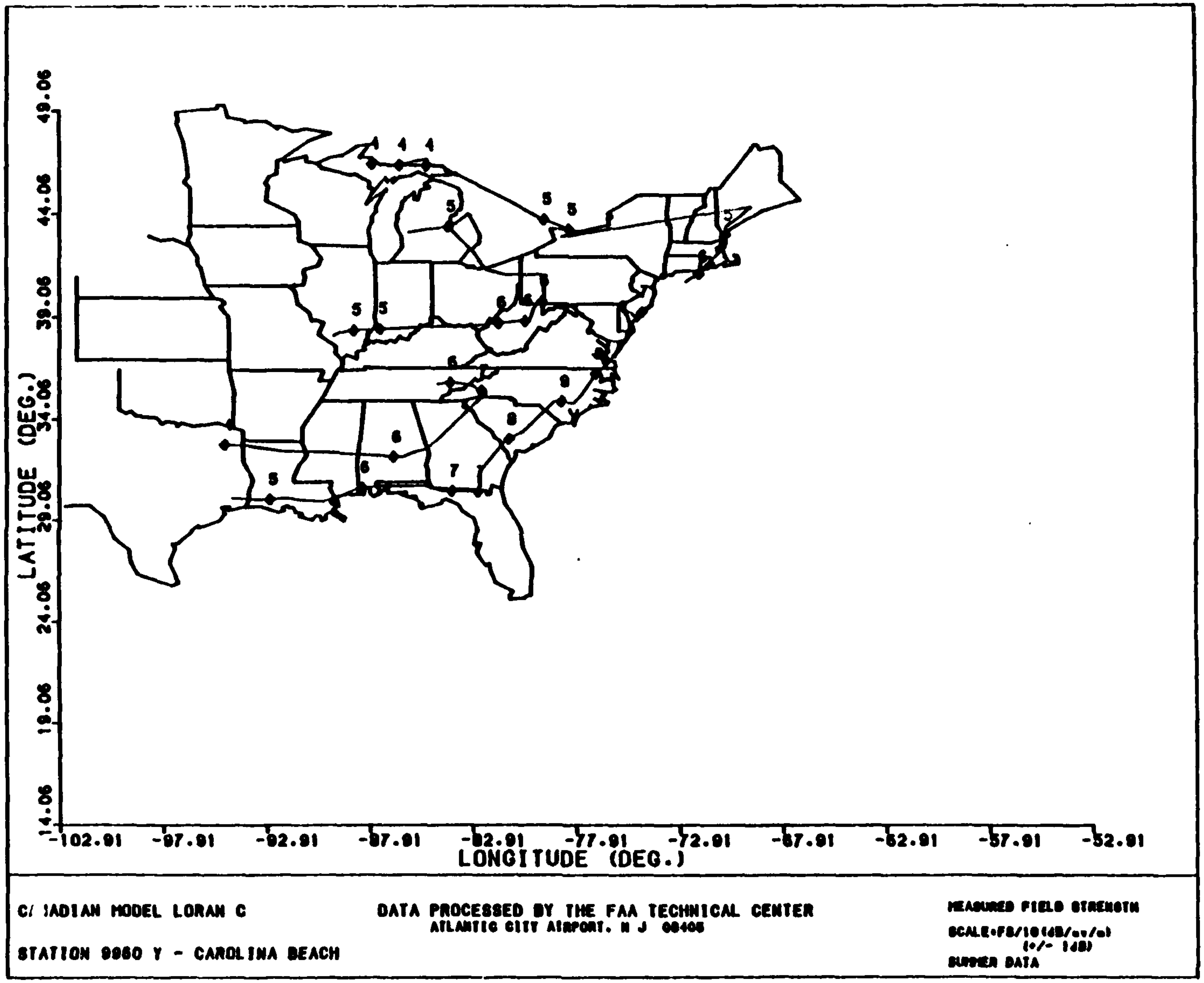


FIGURE A-4. MEASURE) FIELD STRENGTH DATA, CAROLINA BEACH STATION 9960 Y

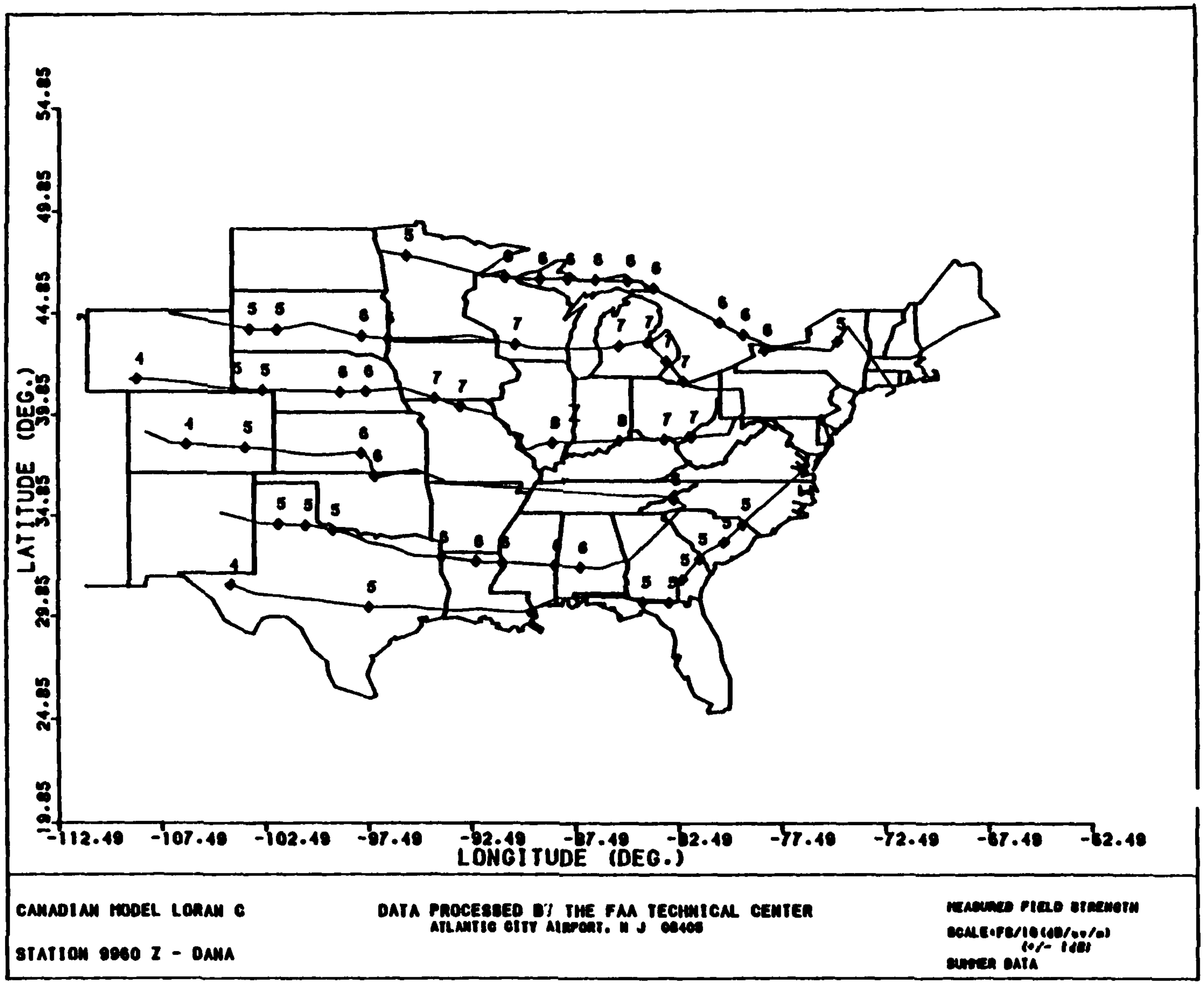


FIGURE A-5. MEASURED FIELD STRENGTH DATA, DANA STATION 9960 Z

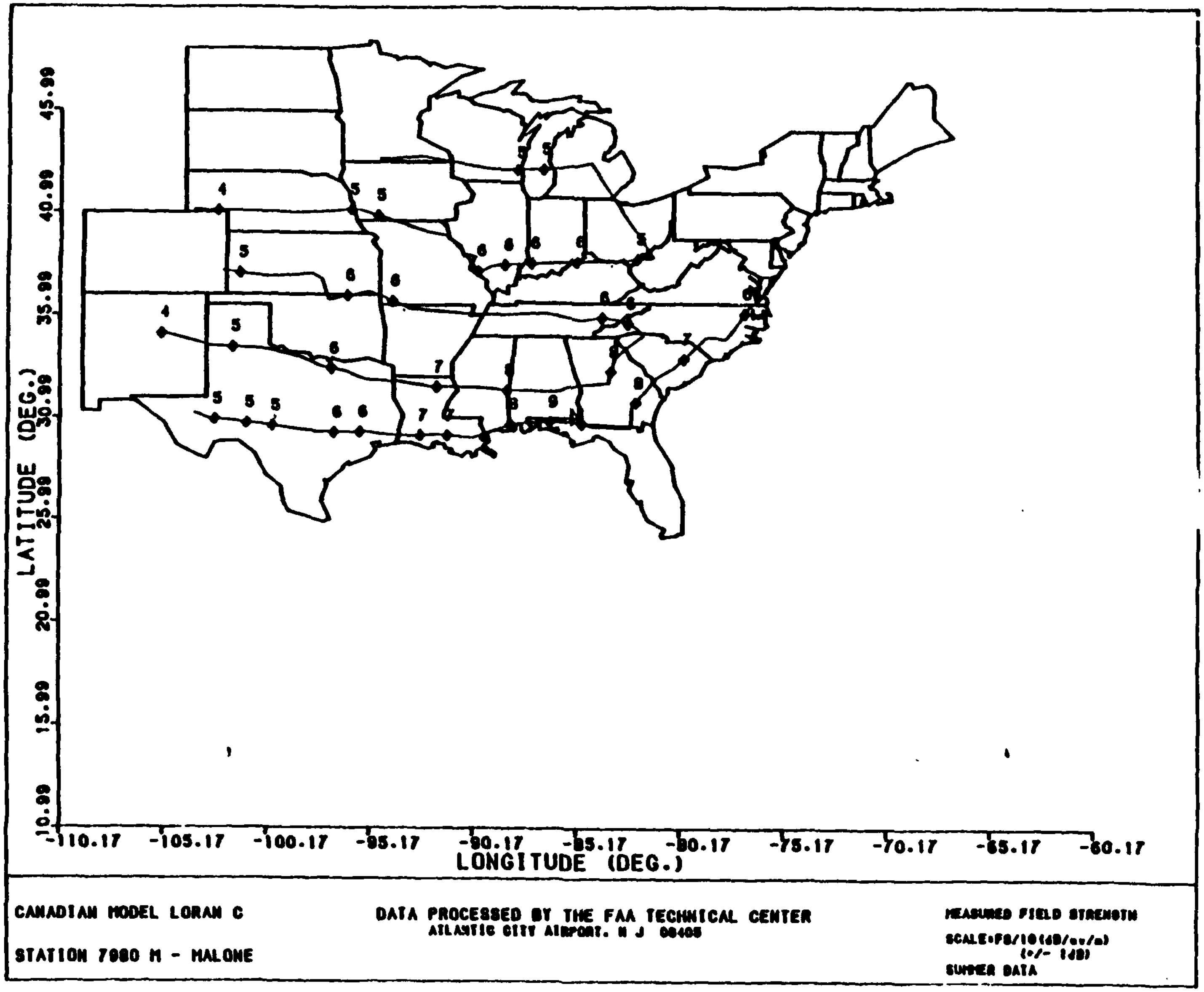


FIGURE A-6. MEASURED FIELD STRENGTH DATA, MALONE STATION 7980 M

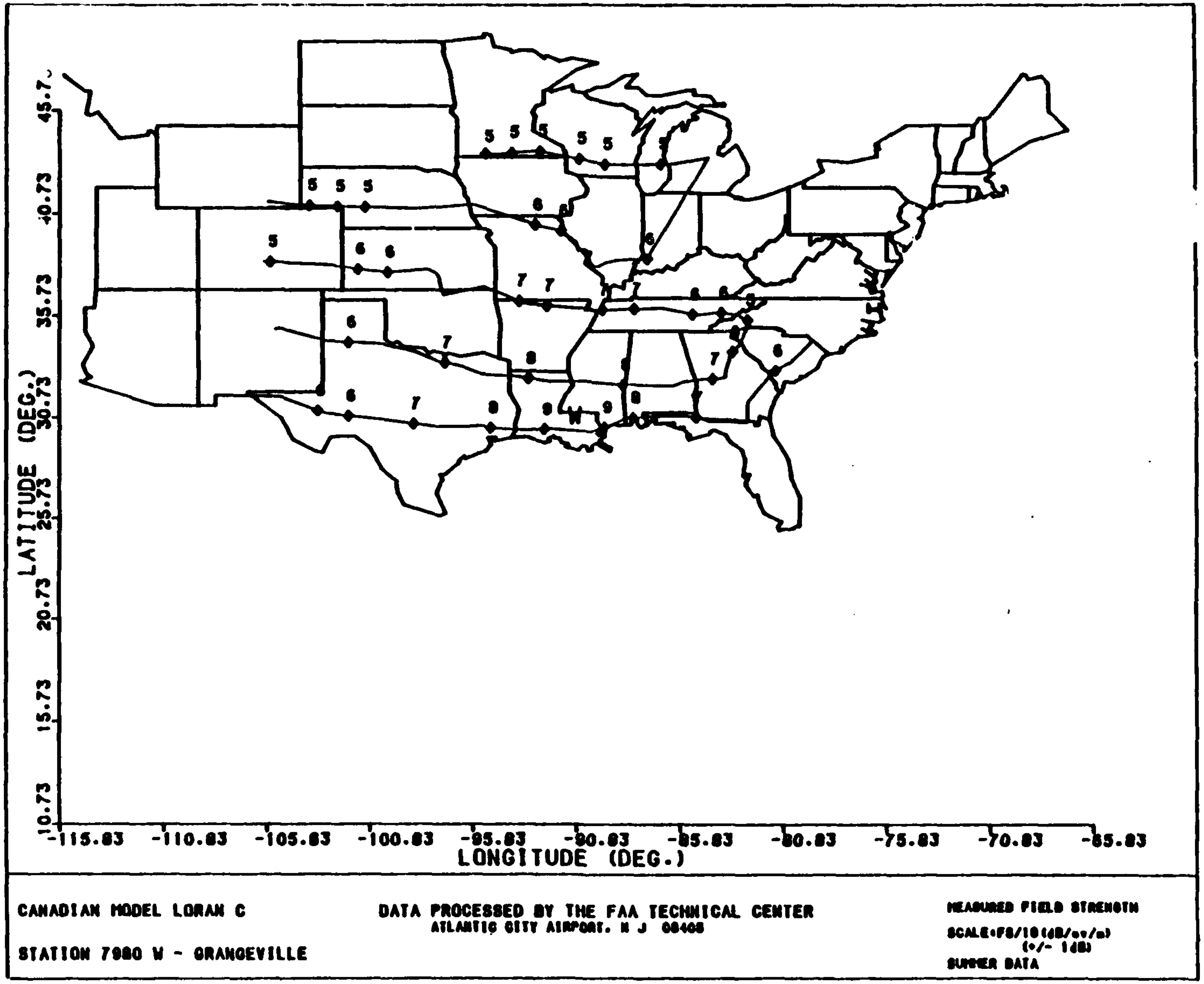


FIGURE A-7. MEASURED FIELD STRENGTH DATA, GRANGEVILLE STATION 7980 W

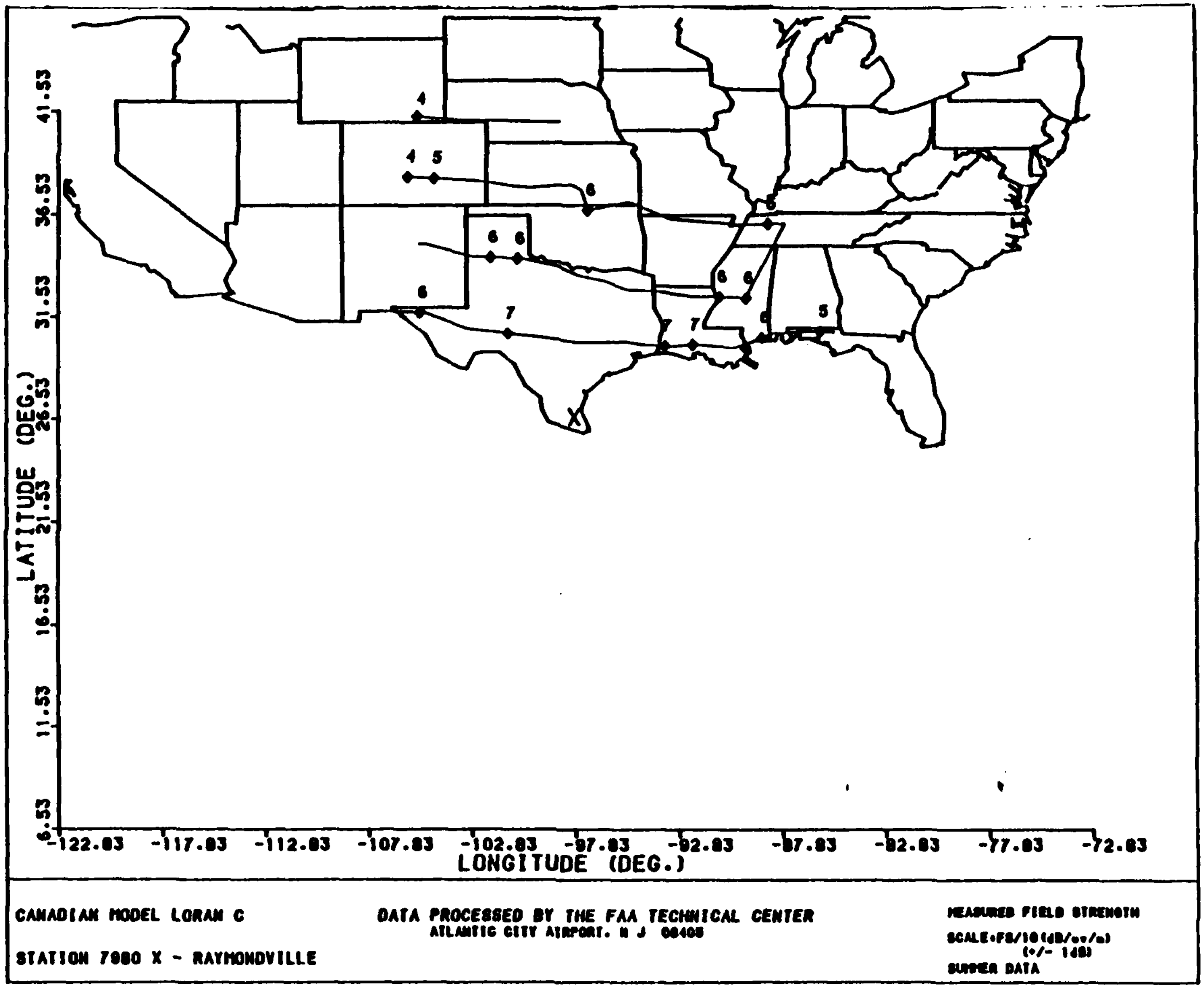


FIGURE A-8. MEASURED FIELD STRENGTH DATA, RAYMONDVILLE STATION 7980 X

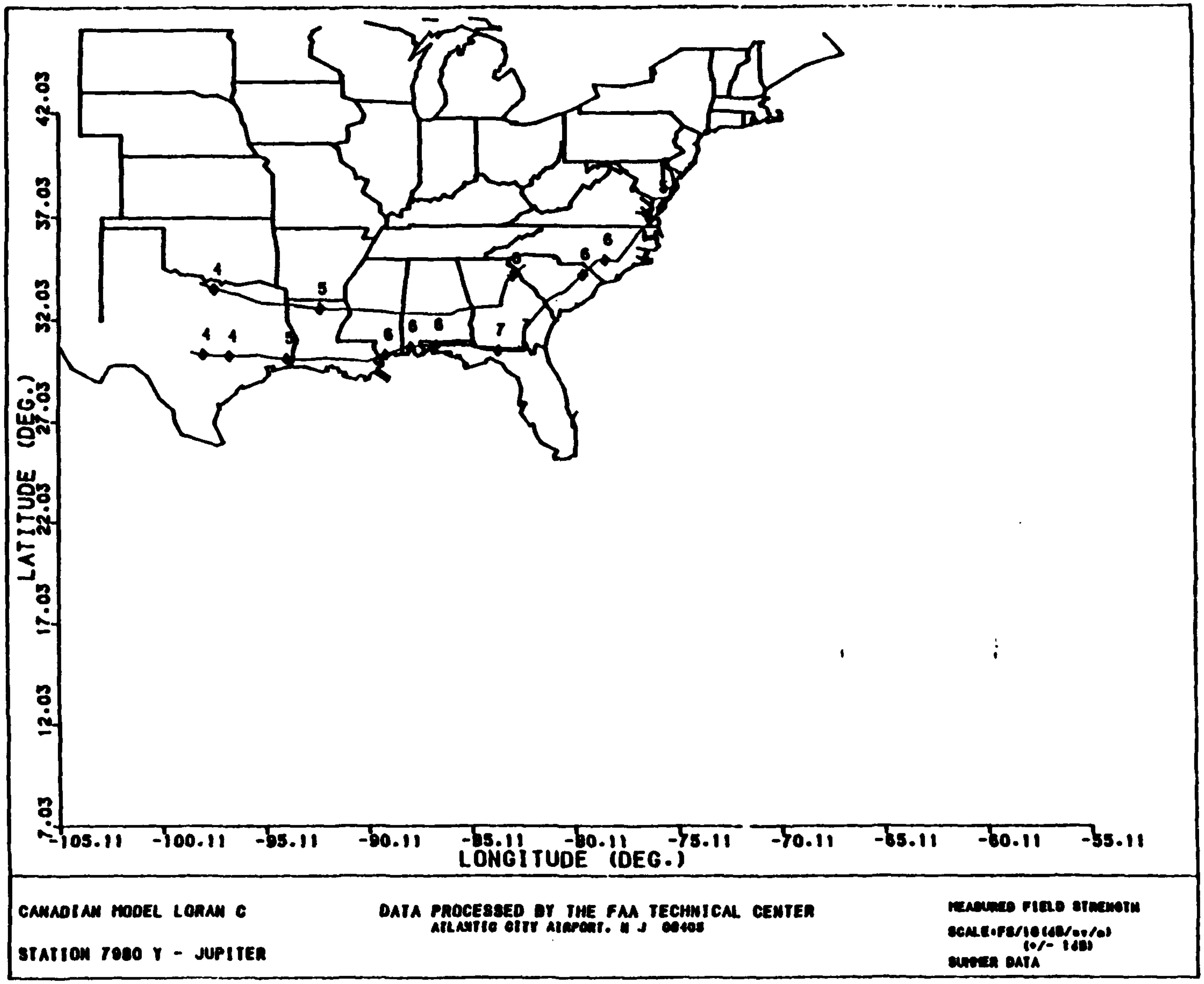


FIGURE A-9. MEASURED FIELD STRENGTH DATA, JUPITER STATION 7980 Y

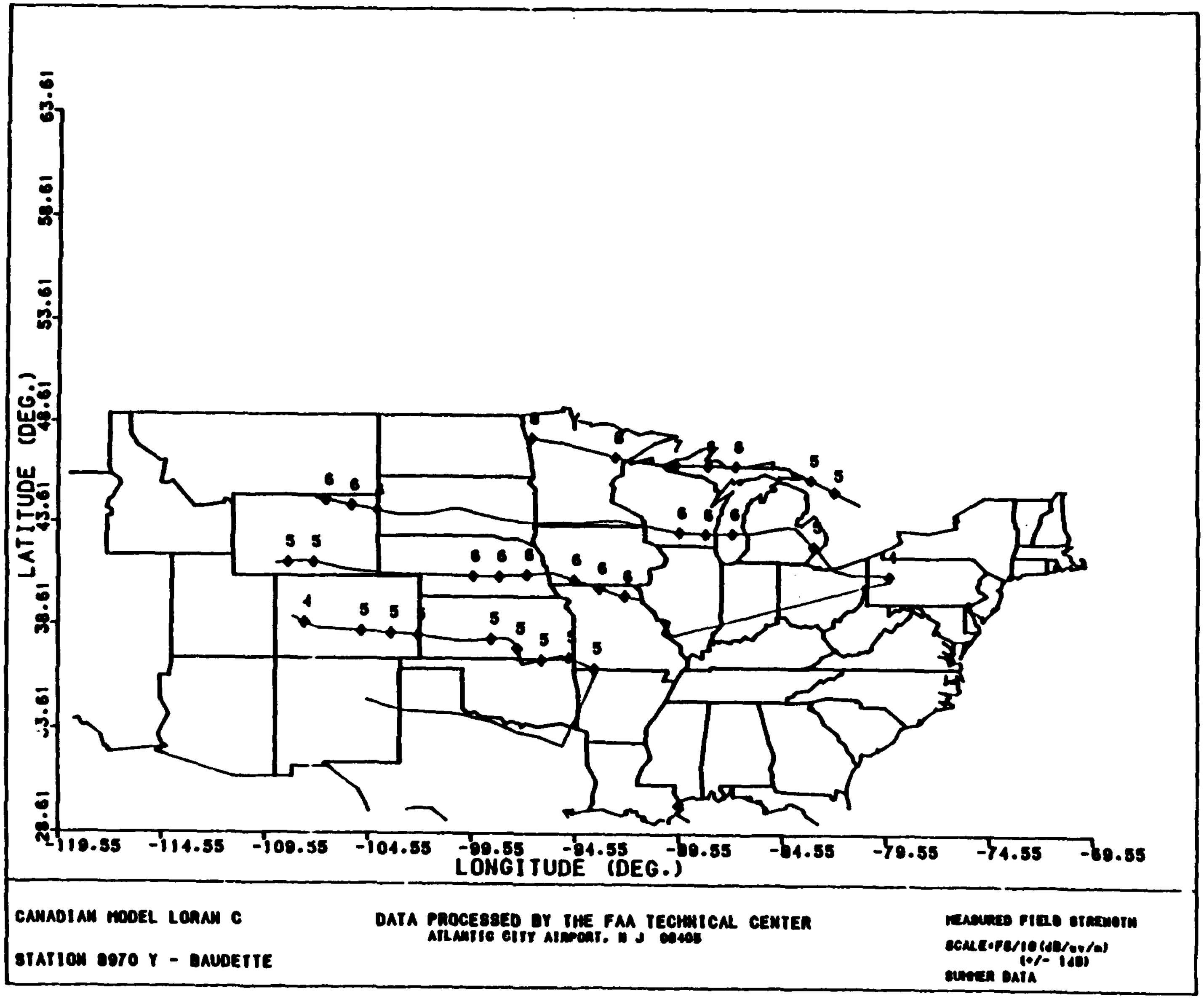


FIGURE A-10. MEASURED FIELD STRENGTH DATA, BAUDETTE STATION 8970 Y

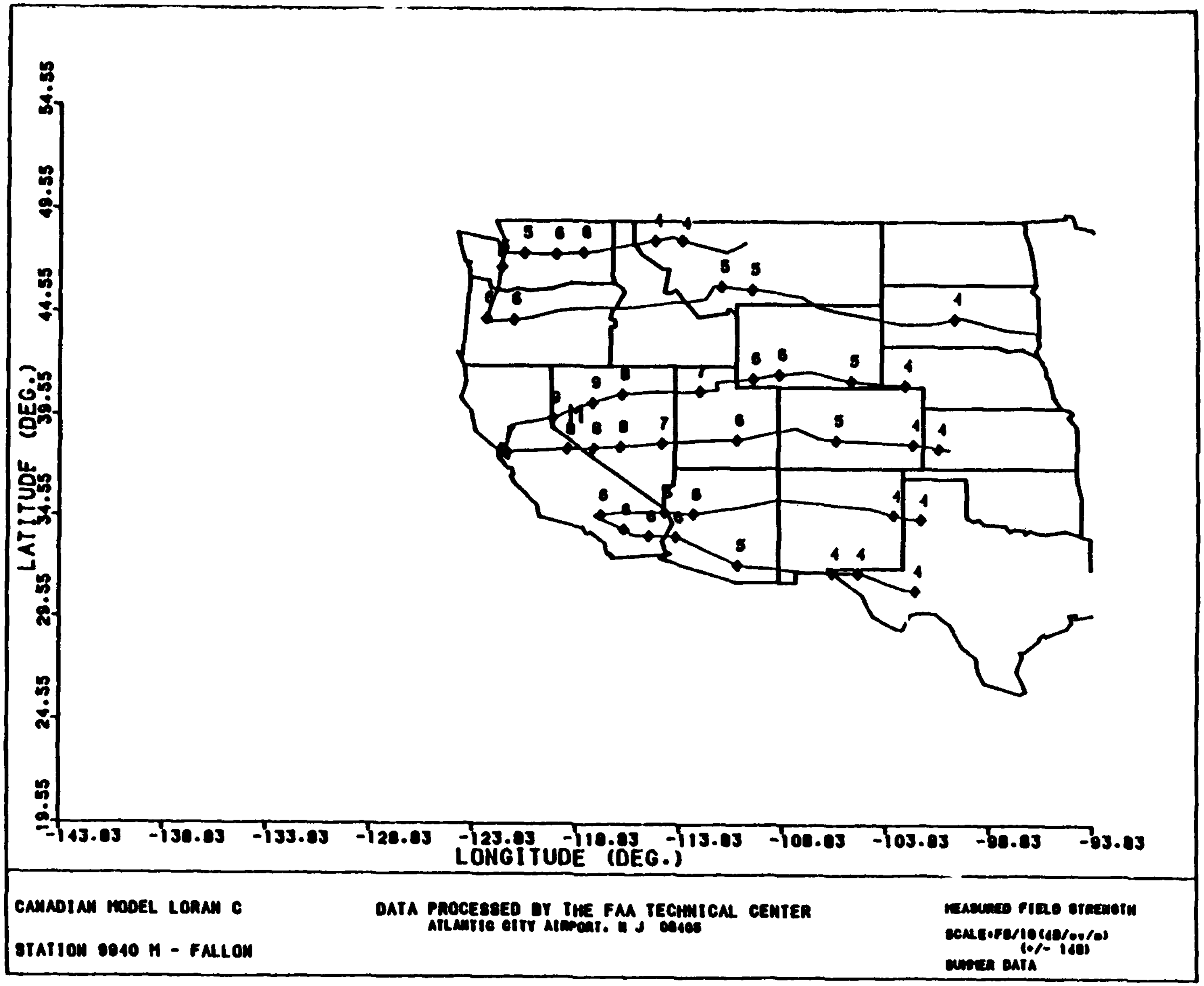


FIGURE A-11. MEASURED FIELD STRENGTH DATA, FALLON STATION 9940 M

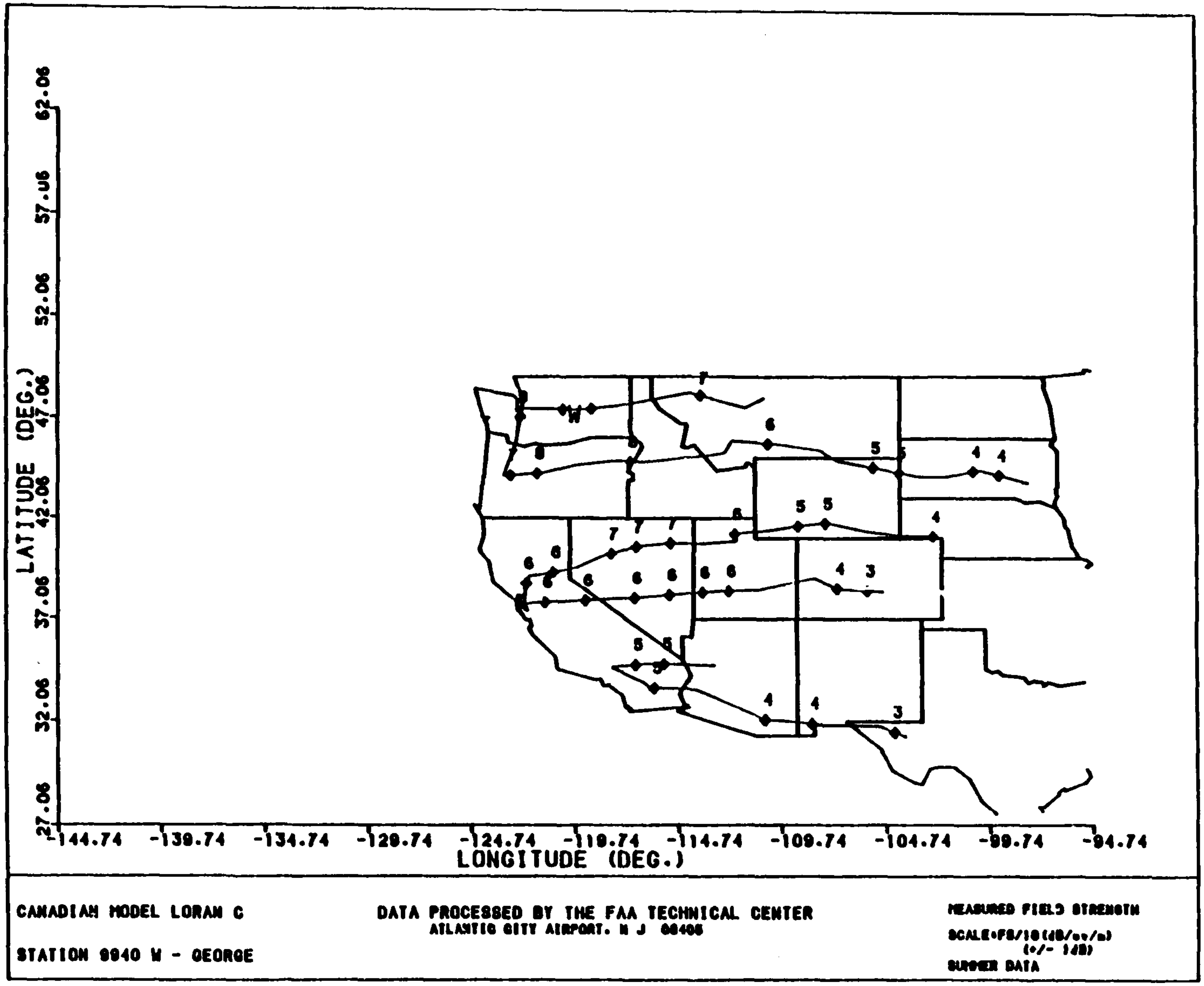


FIGURE A-12. MEASURED FIELD STRENGTH DATA, GEORGE STATION 9940 W

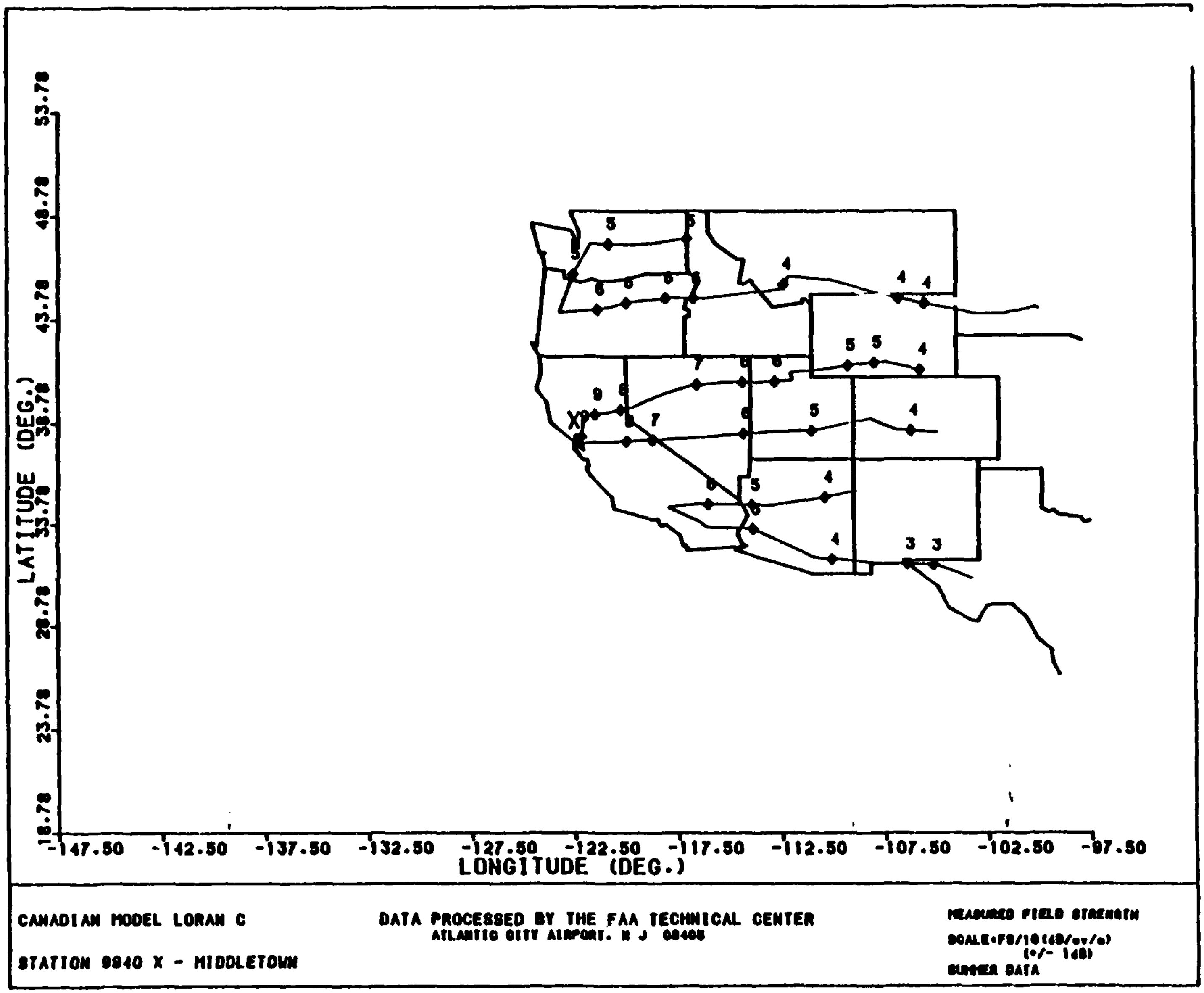


FIGURE A-13. MEASURED FIELD STRENGTH DATA, MIDDLETOWN STATION 9940 X

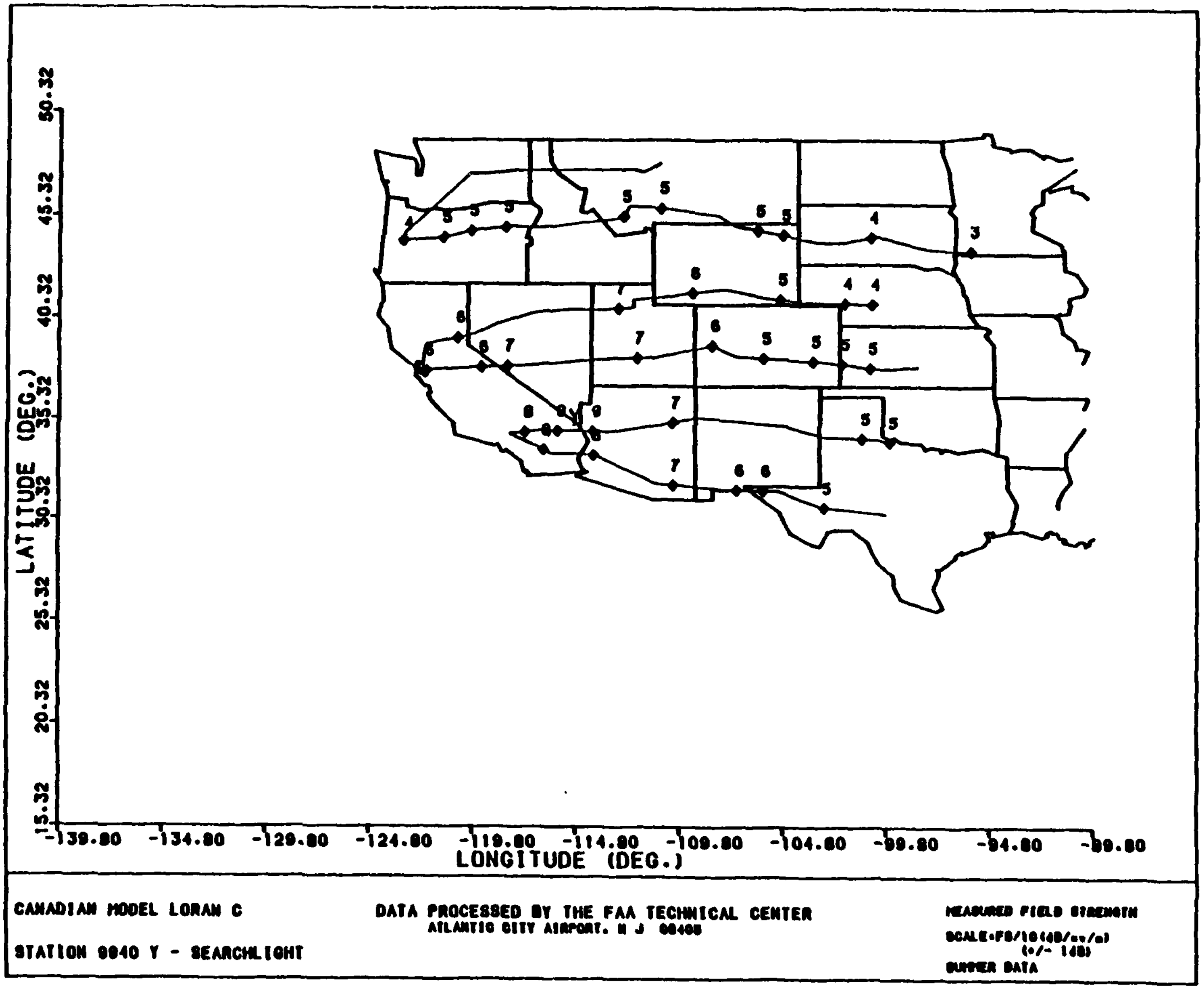


FIGURE A-14. MEASURED FIELD STRENGTH DATA, SEARCHLIGHT STATION 9940 Y

APPENDIX B

MEASURED FIELD STRENGTH DATA VERSUS PREDICTED DATA CONTOUR PLOTS

LIST OF ILLUSTRATIONS

The plots in this appendix show Federal Aviation Administration (FAA) Technical Center's flight measured field strength data along with Canadian Loran C model predicted field strength contours. There is a unique plot for each of the Loran C transmitters listed in table 1.

Data reduction techniques and scaling used for the flight data in the plot are explained in appendix A. Algorithms used to produce the model predicted contours are explained in appendix C. Field strength units are in decibels per microvolt per meter (dB/μV/m). Numbers in the plot are scaled according to the following formula:

field strength / 10; + / - 1.0 dB/μV/m

It is evident from the plots of this appendix that the Canadian software does a good job predicting Loran C field strength. Predicted and measured data usually correspond. Predicted data which does not agree appears within 2 to 5 dB/μV/m of flight measured data.

The visible difference that exists between measured and predicted field strength data may not be as great as it appears. Where a difference exists between predicted and measured field strength values, the model was typically 2 to 5 dB/μV/m higher than the measured values. In part, some of this difference can be attributed to data collection techniques. The Alaska Loran C Probe Test Results technical note (reference 9) indicated a need for an antenna calibration value when measuring field strength in order to obtain a true field strength value. The calibration value is receiver dependent and is computed for distances of 10 to 50 nautical miles (nmi) from a transmitter.

According to the technical note, the average antenna calibration value for the receiver used was 2 dB/μV/m. The antenna calibration values must be added to measured field strength to obtain true field strength values. Because of this phenomenon one would expect model predictions for field strength to be somewhat higher than measured field strength. Adding an antenna calibration value to the measured values would bring the model values and flight test values closer together.

It is evident from the plots in this appendix that the model usually does predict field strength data greater than what was measured along the flight. An exception is in the south and southeast area. Here, the model predicts a field strength less than expected. This occurs because of the poor conductivity values employed for this region by the software.

Plots in this appendix are grouped by Loran C chain. Some stations are dual rated, that is they are configured and function in two different chains. Radiated power remains the same, therefore plots of stations which are dual rated appear once in the appendix. Figures B-1 through B-5 of this appendix compare measured field strength data with predicted contours of the Northeast 9960 Loran C transmitters. Data are compared along the flightpath for each of the indicated stations. Figures B-6 through B-9 are plots for the Southeast 7980 chain. Figure B-10 is data for the Great Lakes station 8970 Y. Field strength data for stations of the West Coast chain are shown in figures B-11 through B-14.

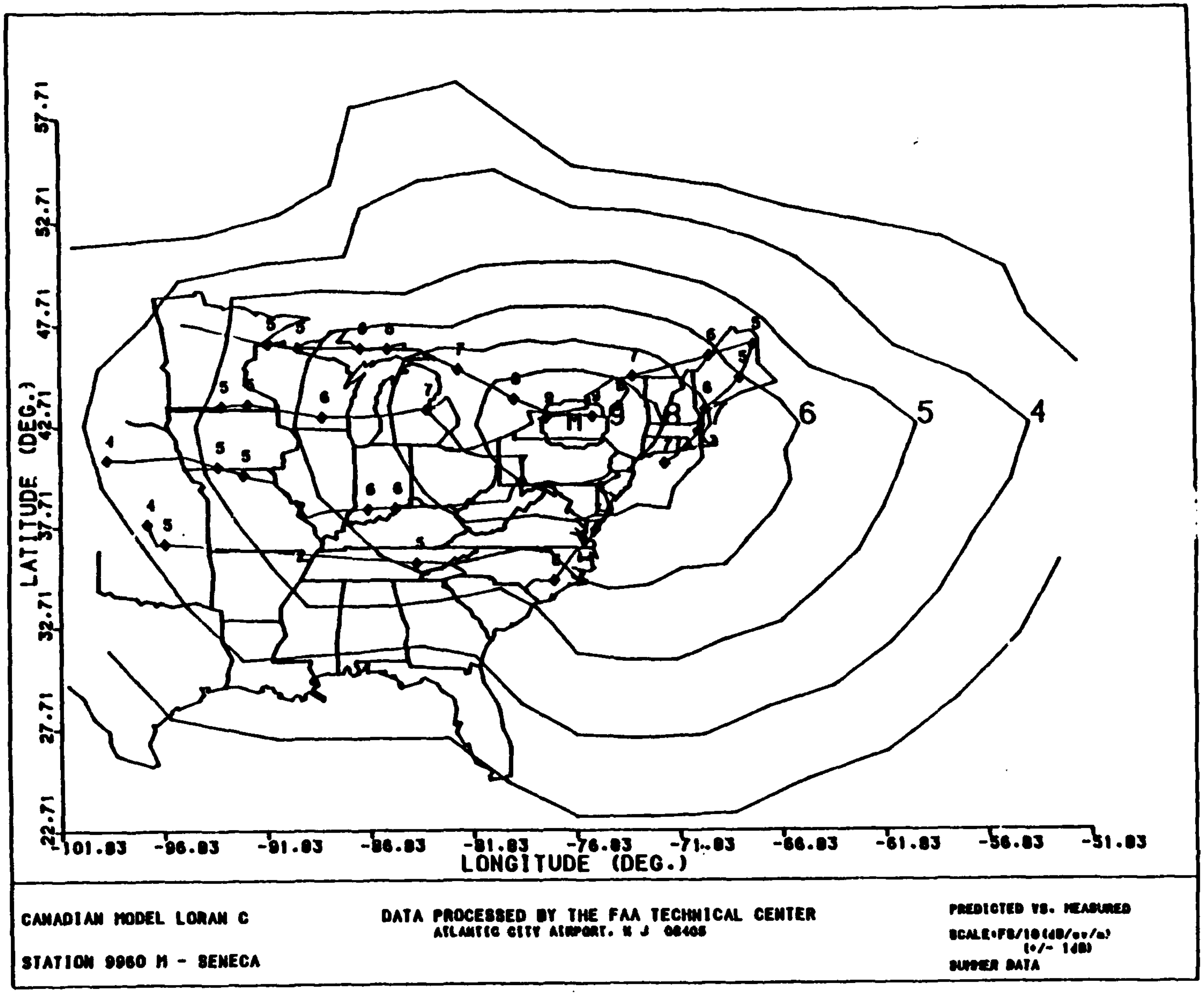


FIGURE B-1. MEASURED VERSUS PREDICTED DATA, SENECA STATION 9960 M

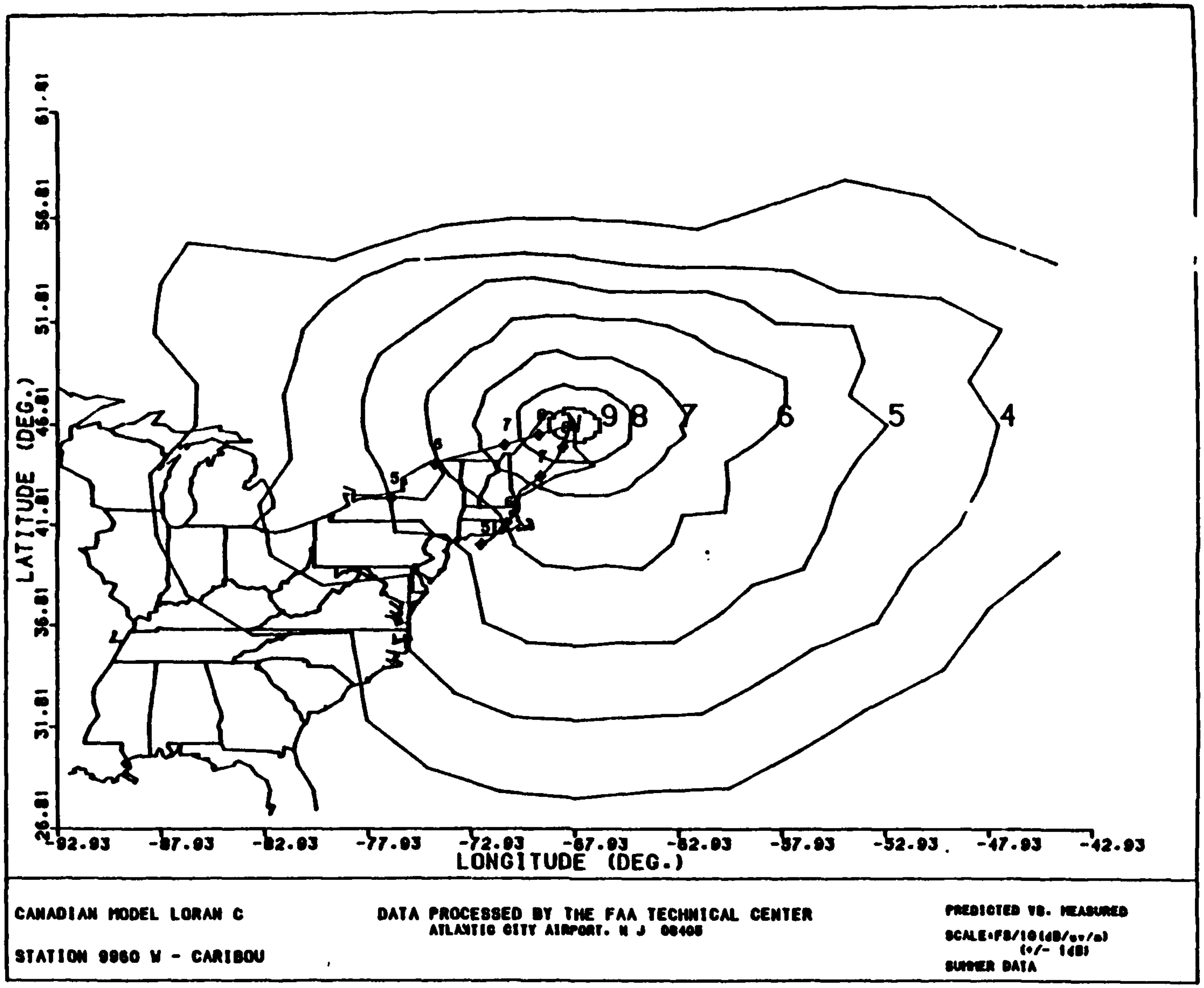


FIGURE B-2. MEASURED VERSUS PREDICTED DATA, CARIBOU STATION 9960 W

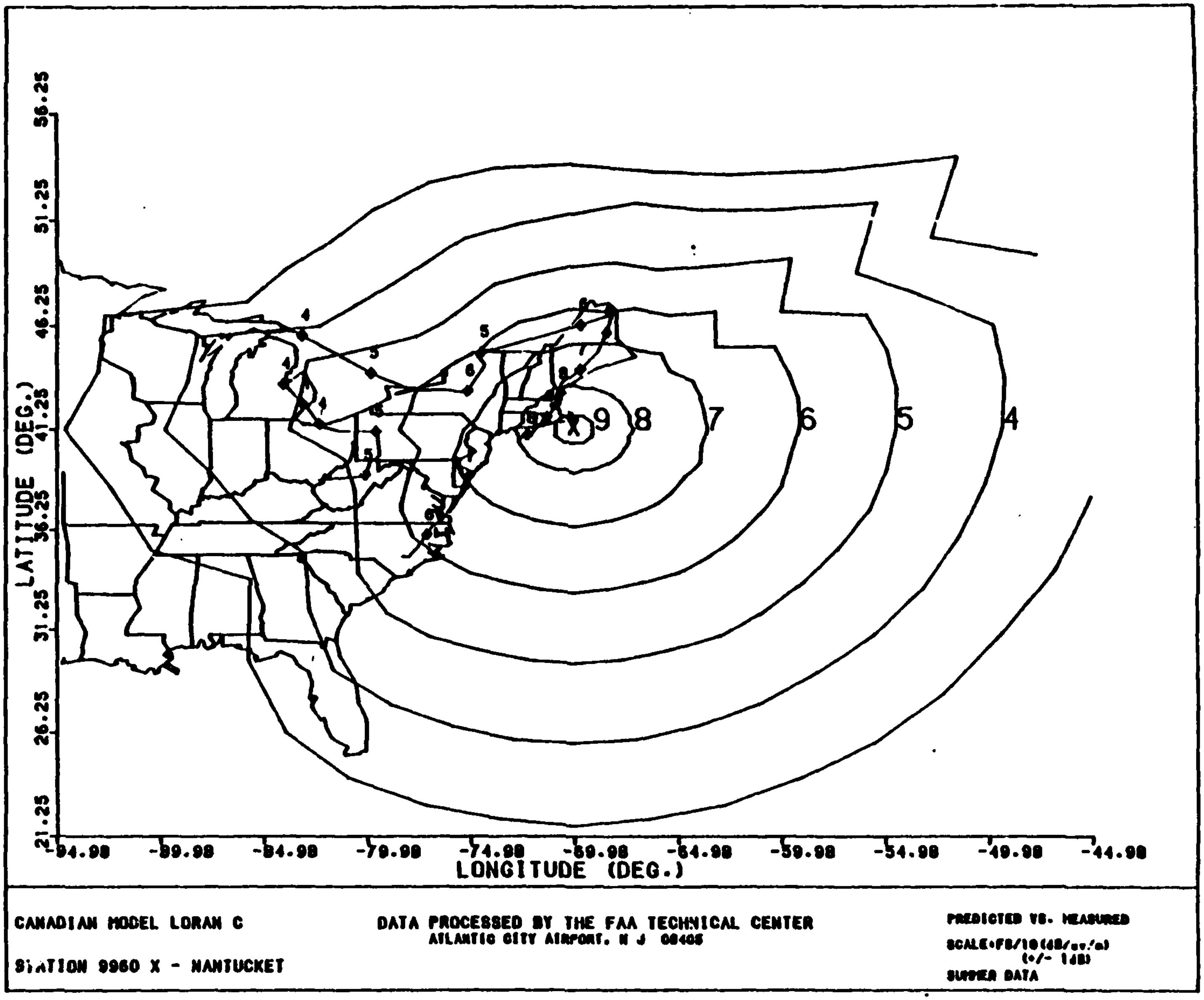


FIGURE B-3. MEASURED VERSUS PREDICTED DATA, NANTUCKET STATION 9960 X

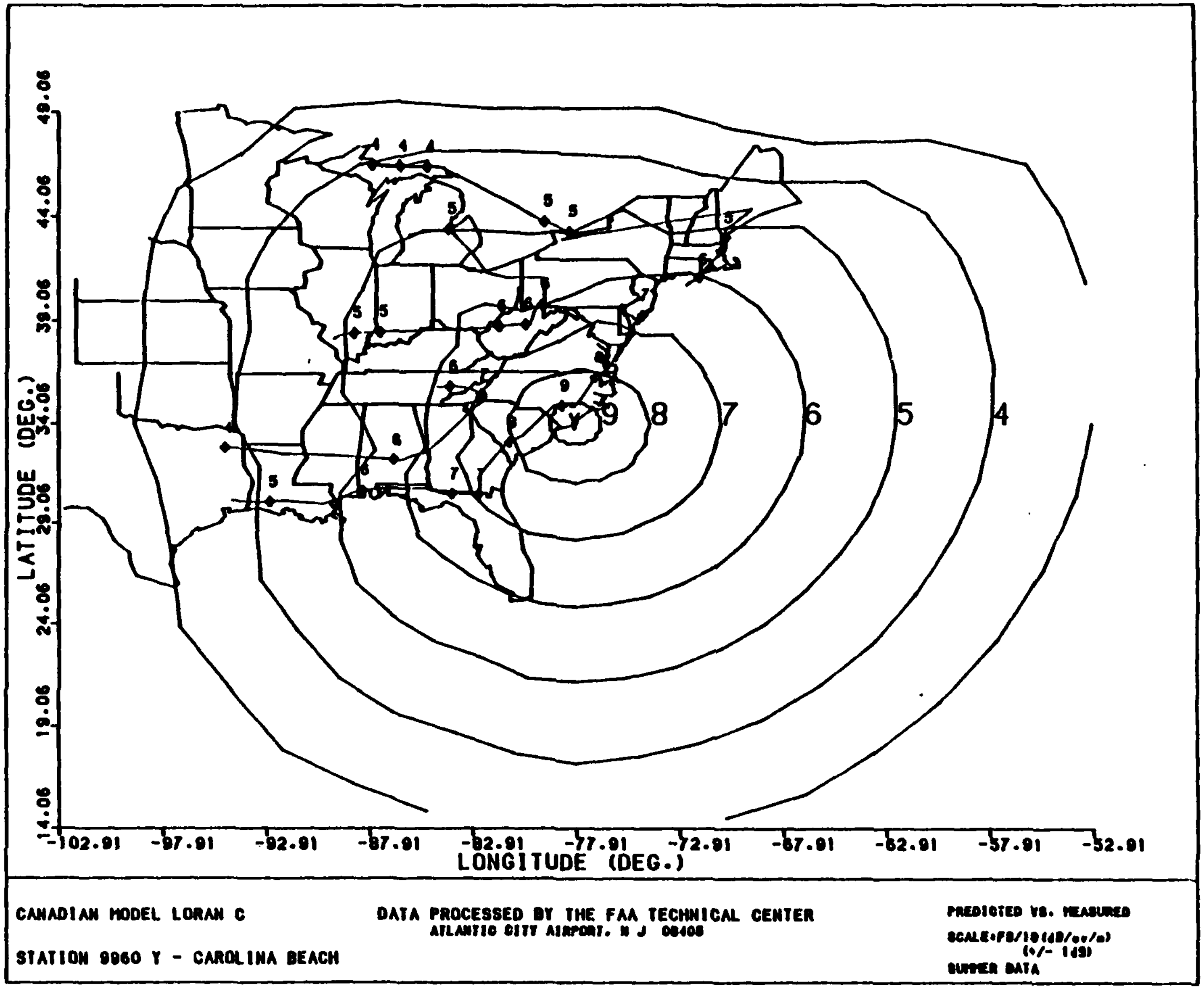
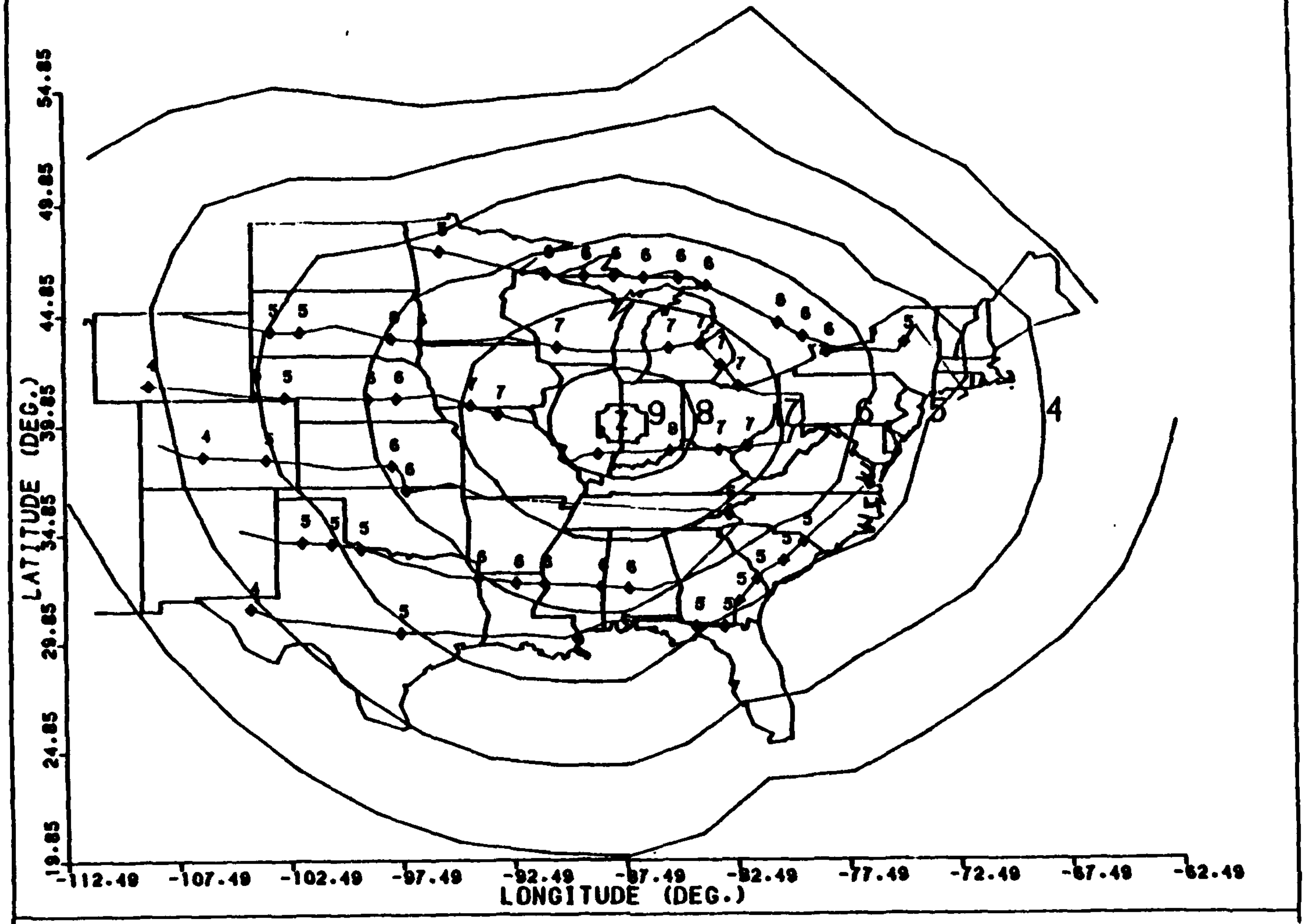


FIGURE B-4. MEASURED VERSUS PREDICTED DATA, CAROLINA BEACH STATION 9960 Y



CANADIAN MODEL LORAN C

STATION 9960 Z - DANA

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

PREDICTED VS. MEASURED
SCALE:Fb/10(dB/uv/m)
(+/- 1dB)
SUMMER DATA

FIGURE B-5. MEASURED VERSUS PREDICTED DATA, DANA STATION 9960 Z

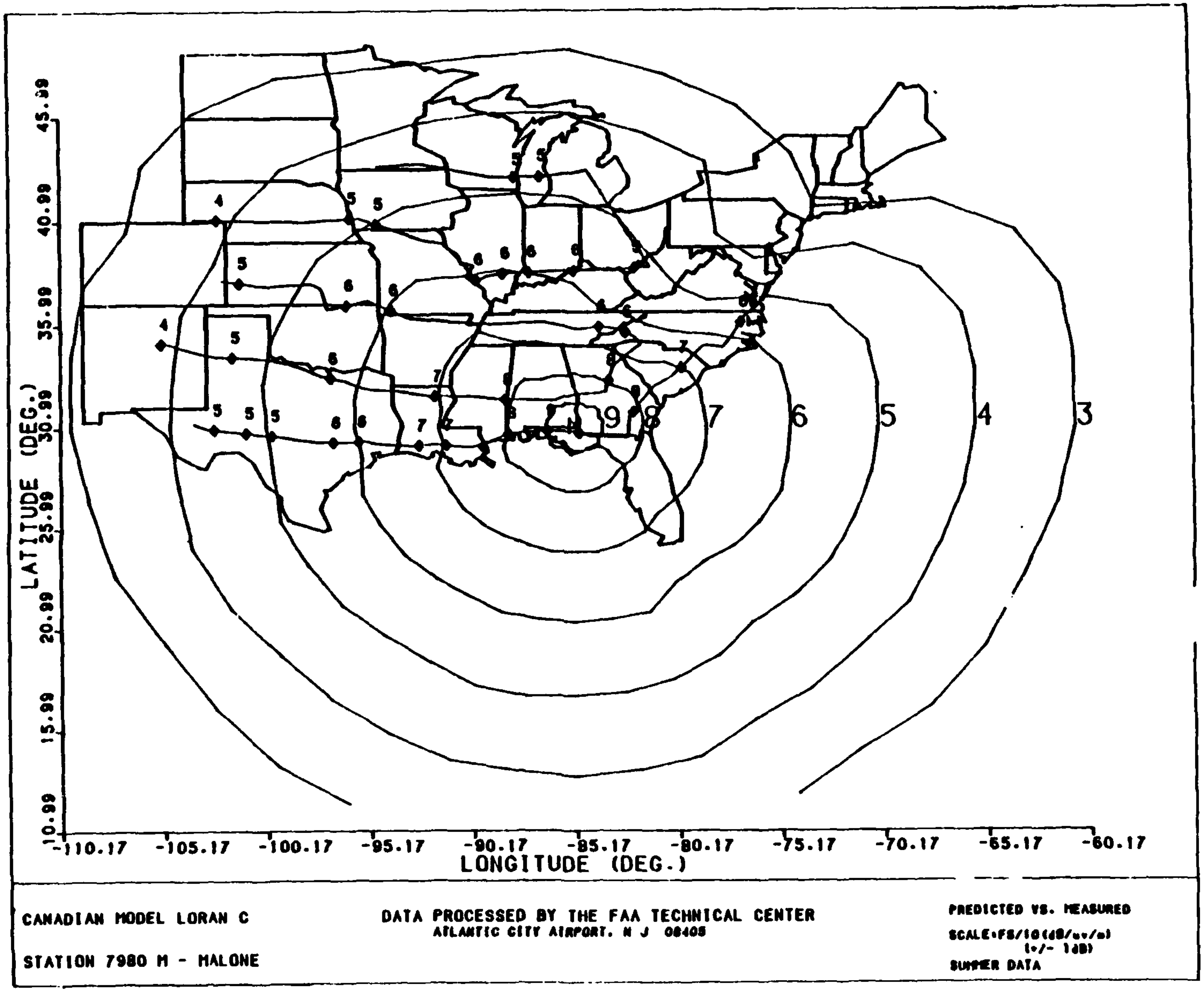


FIGURE B-6. MEASURED VERSUS PREDICTED DATA, MALONE STATION 7980 M

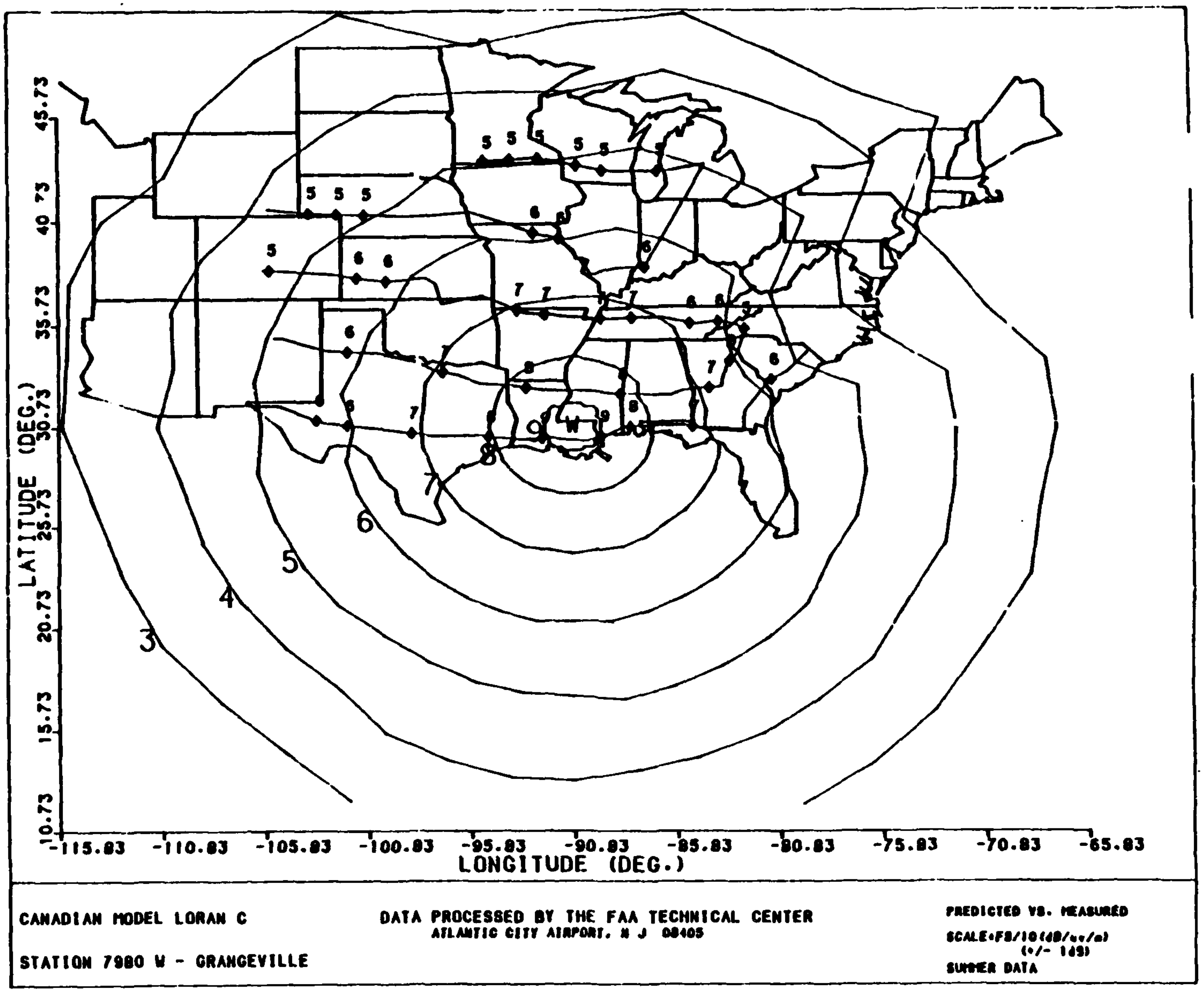


FIGURE B-7. MEASURED VERSUS PREDICTED DATA, GRANGEVILLE STATION 7980 W

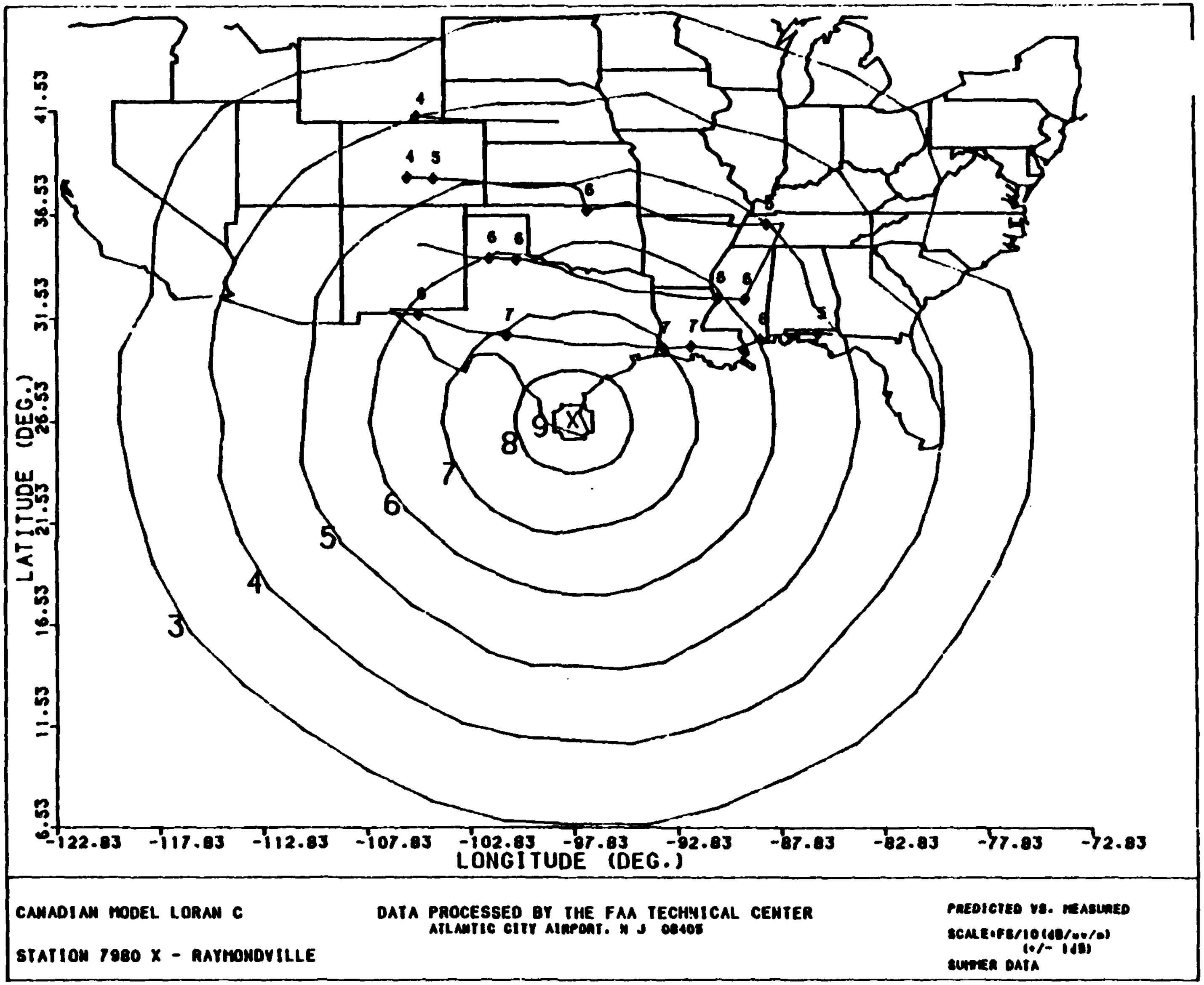


FIGURE B-8. MEASURED VERSUS PREDICTED DATA, RAYMONDVILLE STATION 7980 X

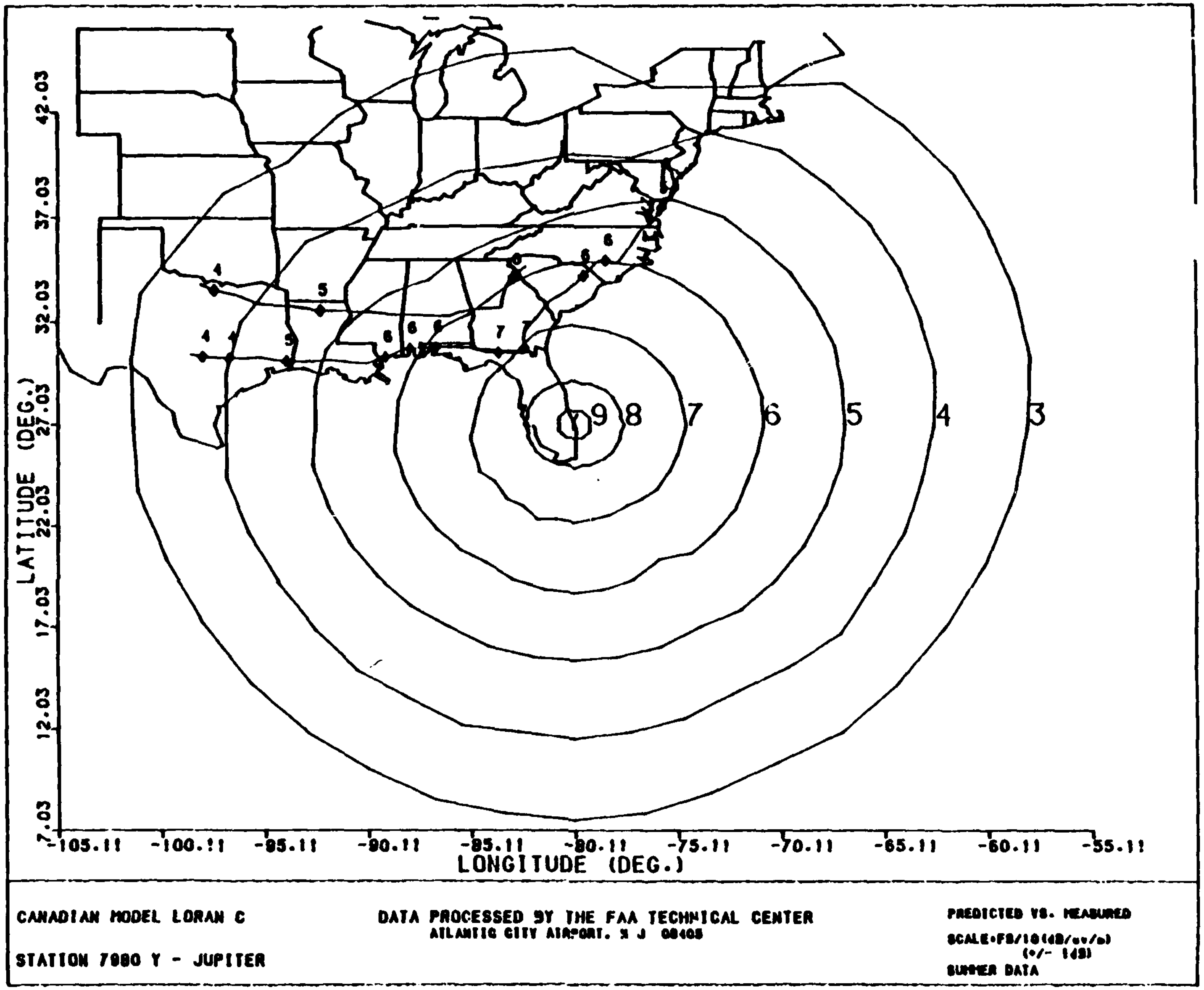


FIGURE B-9. MEASURED VERSUS PREDICTED DATA, JUPITER STATION 7980 Y

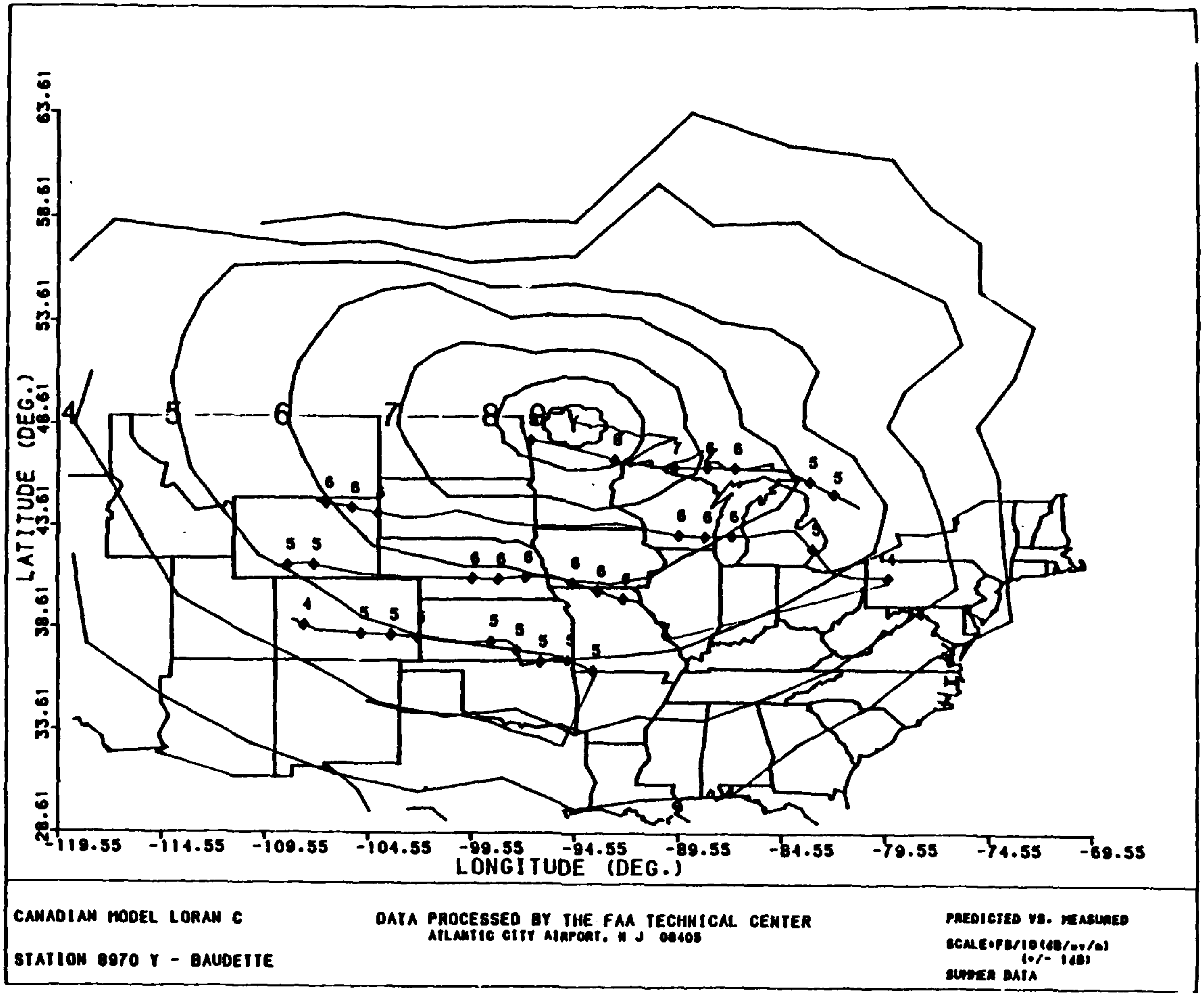


FIGURE B-10. MEASURED VERSUS PREDICTED DATA, BAUDETTE STATION 8970 Y

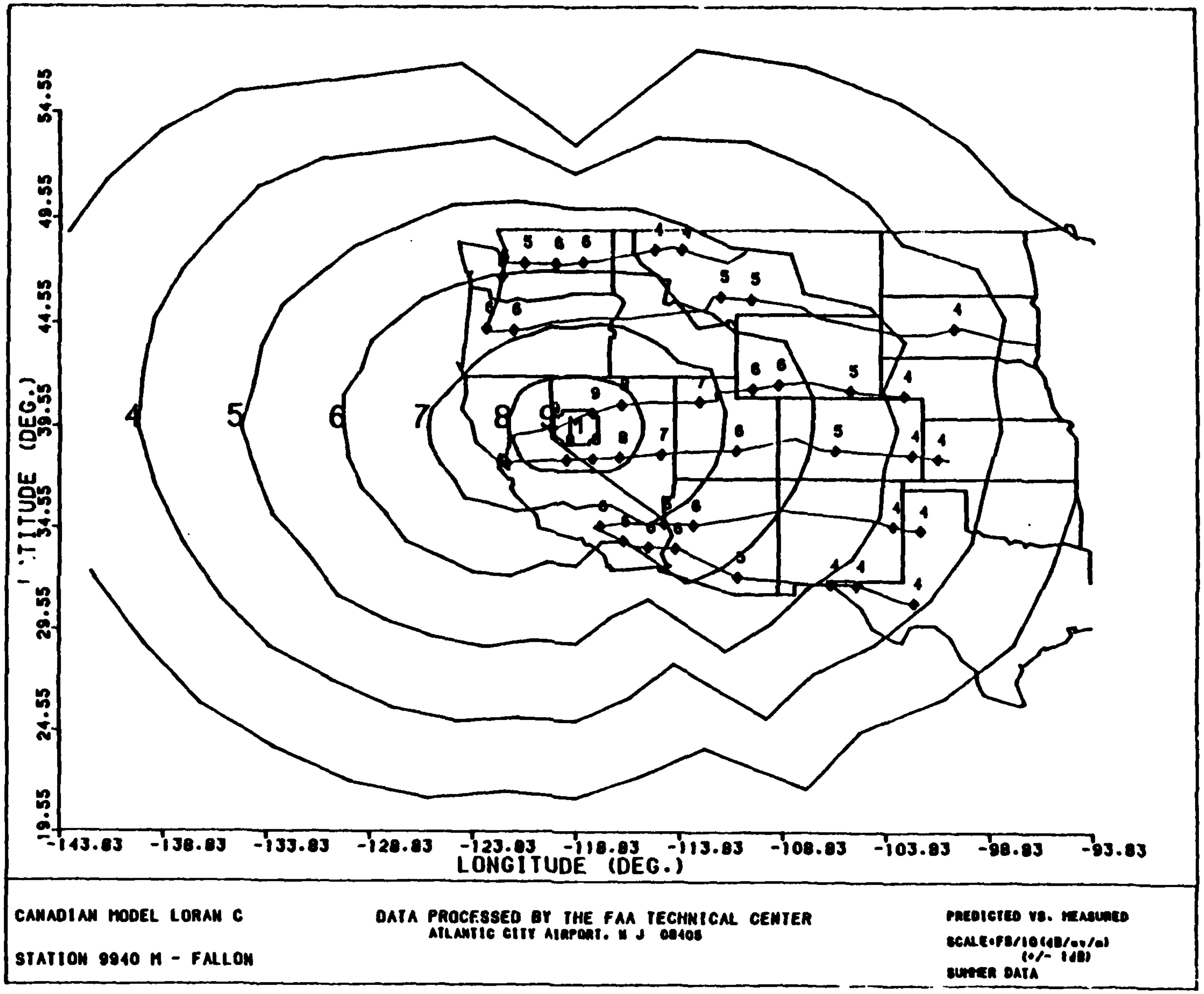


FIGURE B-11. MEASURED VERSUS PREDICTED DATA, FALLON STATION 9940 M

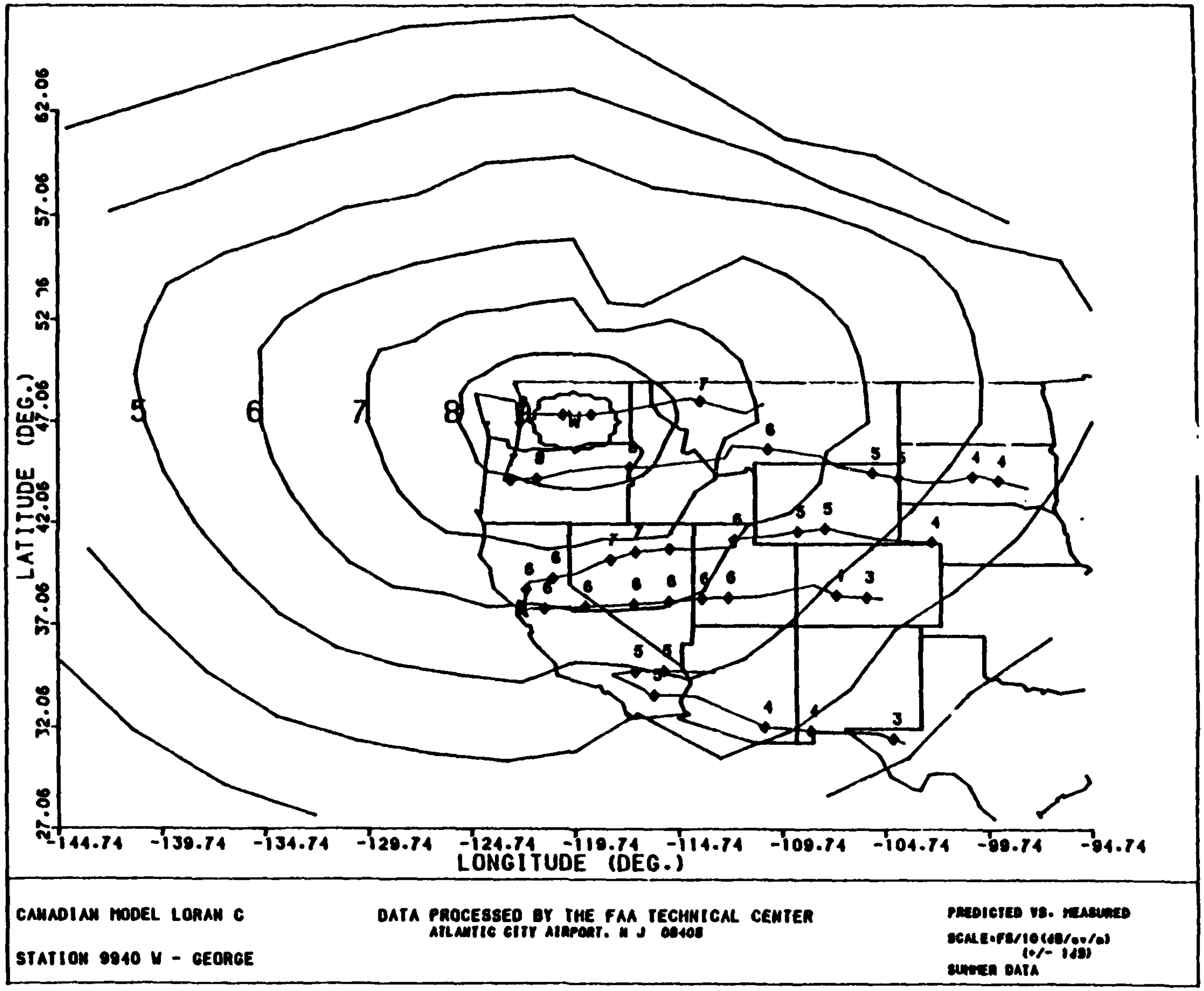


FIGURE B-12. MEASURED VERSUS PREDICTED DATA, GEORGE STATION 9940 W

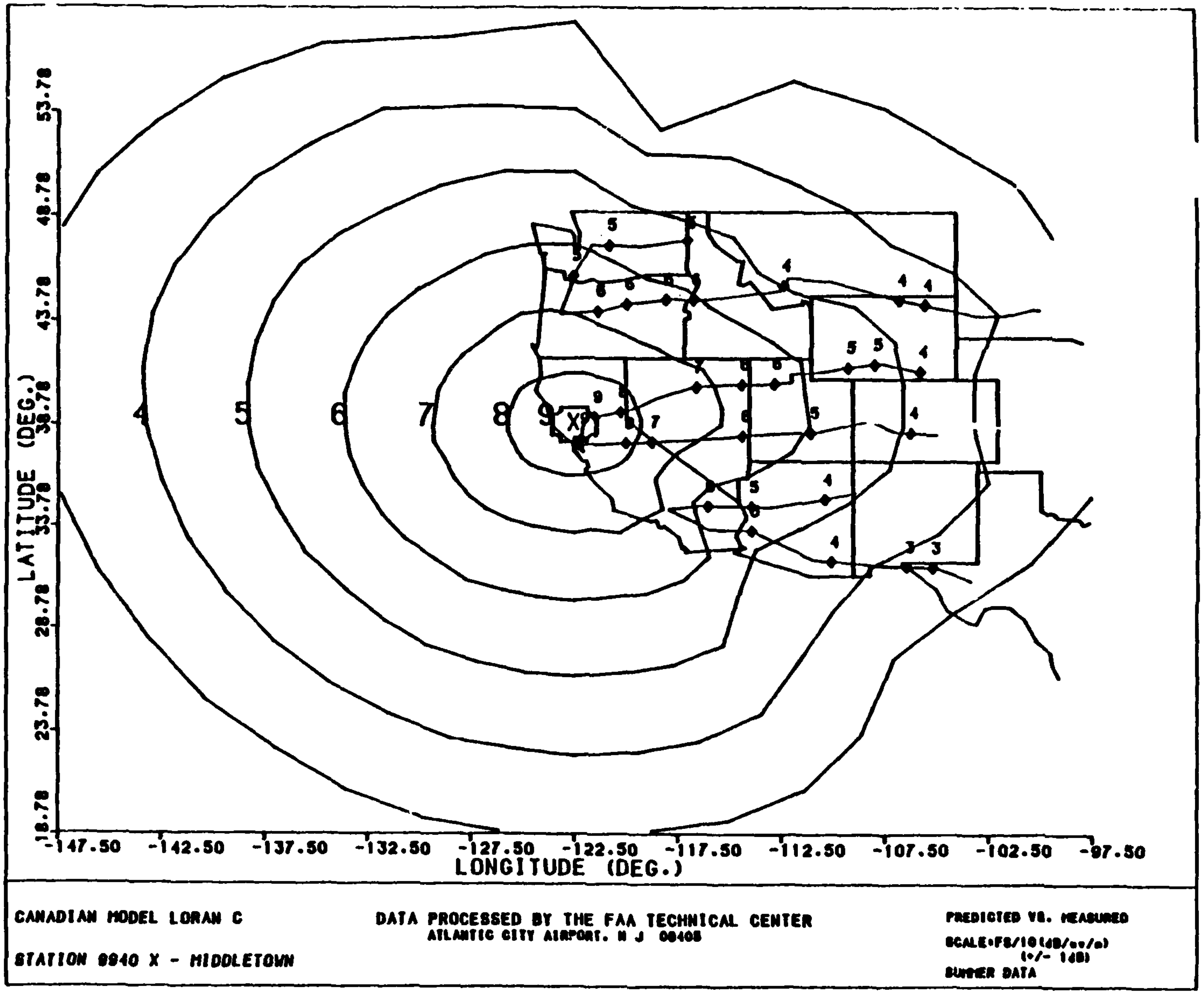


FIGURE B-13. MEASURED VERSUS PREDICTED DATA, MIDDLETOWN STATION 9940 X

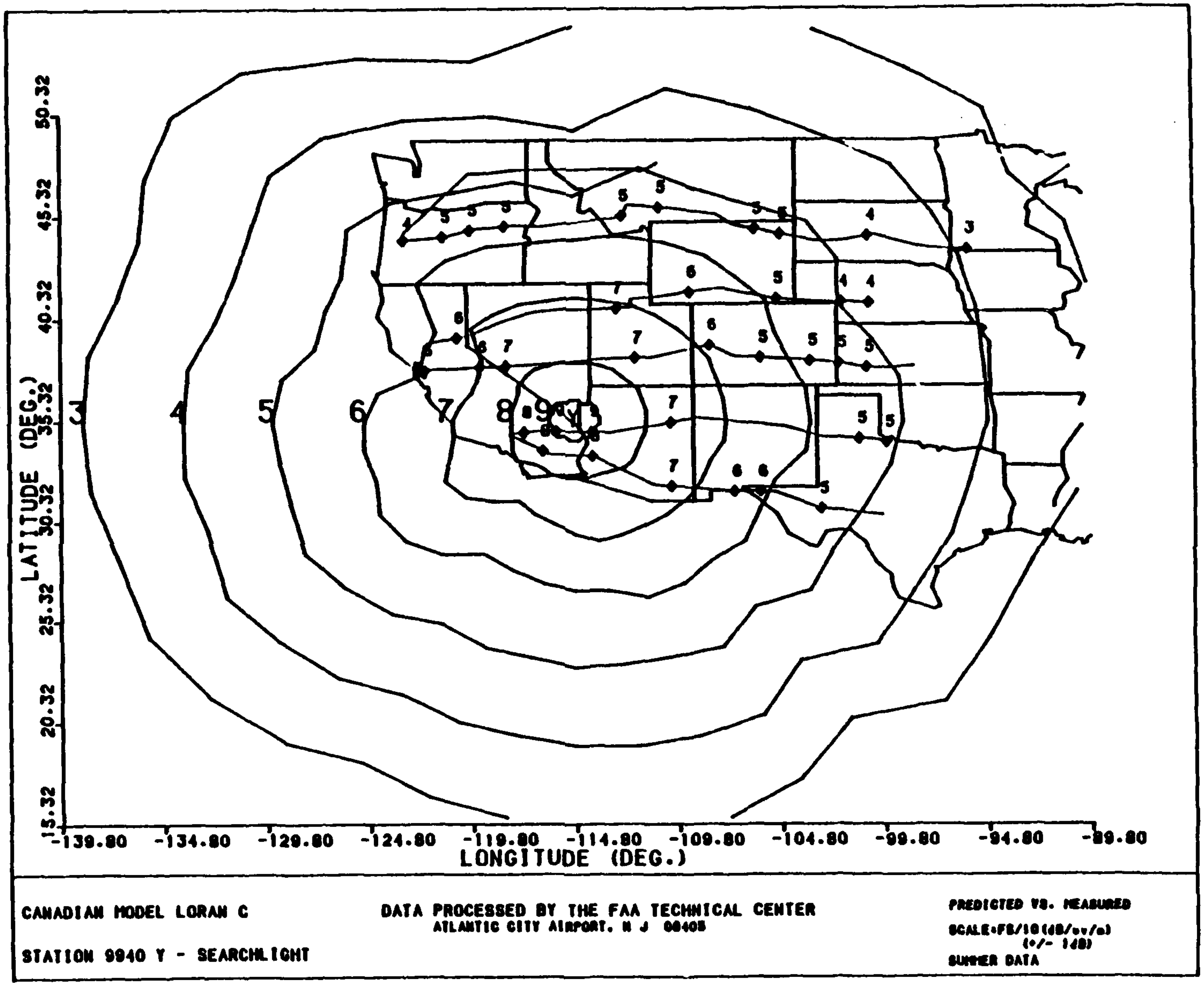


FIGURE B-14. MEASURED VERSUS PREDICTED DATA, SEARCHLIGHT STATION 9940 Y

APPENDIX C

PREDICTED FIELD STRENGTH CONTOUR PLOTS

LIST OF ILLUSTRATIONS

The plots in this appendix show predicted Loran C field strength contours throughout the contiguous United States (CONUS). There are 19 plots. The first 14 plots show contours of Loran C transmitters which are presently in operation. Predicted field strength contours are also shown for the new mid-west chains which are not yet operational. Parameters for predicting signal strength include transmitter power, path conductivity, and distance from transmitter. Table 1 lists the transmitter powers used for calculating field strength. Figure 4 shows the CONUS conductivities employed and figure 7 shows the ground wave field intensity graphs used by the model for prediction.

The Canadian Loran C propagation model was modified so that predicted field strength could be output based on distance from a transmitter. A polar coordinate system was used to evaluate field strength attenuation as distance was increased from a transmitter to a receiver. Starting at the transmitter, 1500 nautical mile (nmi) radials were simulated. The first radial extended north from the transmitter. A simulated receiver was located 10 nmi. from the transmitter along the radial. The transmitter-receiver's path was divided into electrically homogeneous segments of the same conductivity using the MORGAN conductivity map shown in figure 4. Millington's method for calculating field strength was then applied to predict the received signal strength at that location.

The receiver was then located 20 nmi from the transmitter along the same radial. The above algorithm was applied in like manner. Every 10 nmi, along the 1500 nmi radial, was evaluated for received signal strength.

The next radius vector evaluated was 10° clockwise from north, again with the transmitter at the pole. There were a total of 36 radials about the transmitter tested for field strength attenuation. Each radial was generated 10° clockwise from the former with the transmitter at the pole.

A data base was built to generate field strength contours for each of the CONUS Loran C transmitters which included:

1. receiver position in polar coordinates (rotational angle and distance from transmitter)

2. receiver position in rectangular coordinates (latitude/longitude)

3. transmitter position (latitude/longitude)

4. transmitter-receiver distance in nmi, and-

5. predicted field strength in dB/μV/m.

From this data base, the contours of appendix C were plotted. Plots are grouped by Loran C chain. Some stations are dual rated, that is, they are configured and function in two different chains. Radiated power remains the same, therefore plots of stations which are dual rated appear once in the appendix. Figures C-1 through C-5 are predicted field strength contours of the Northeast 9960 chain transmitters. Data are plotted for each of the indicated stations. Figures C-6 through C-9 are predicted field strength plots for the Southeast 7980 chain. Figure C-10 is data for the Great Lakes station 8970 Y. Field strength data for stations of the West Coast chain are shown in figures C-11 through C-14.

Also included are plots of predicted field strength contours for station of the new North Central and South Central chains. Figures C-15 through C-19 are predicted contours for the mid-west stations Las Cruces, Havre, Williams Lake, Boise City, and Gillette.

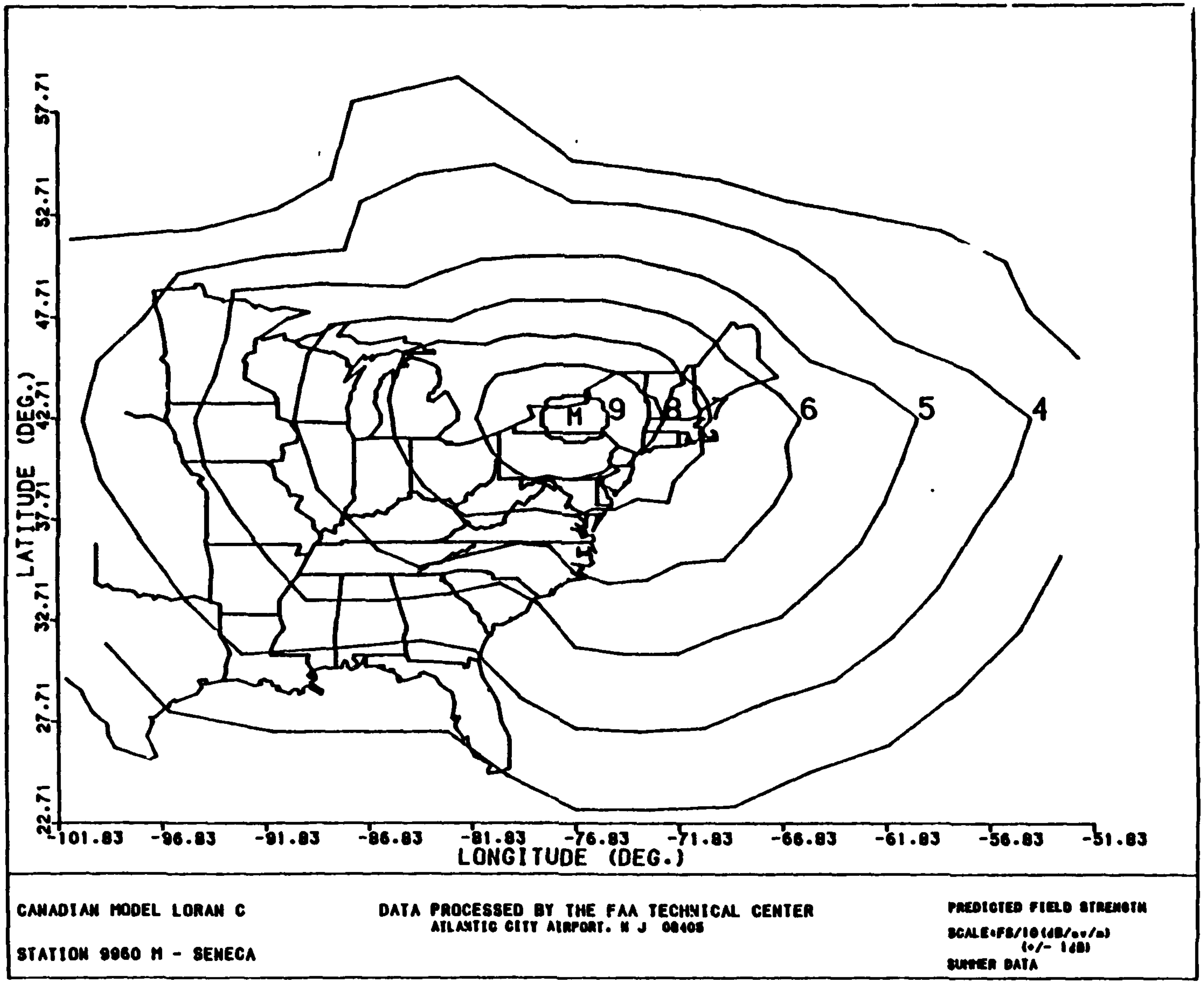


FIGURE C-1. PREDICTED FIELD STRENGTH CONTOURS, SENECA STATION 9960 M

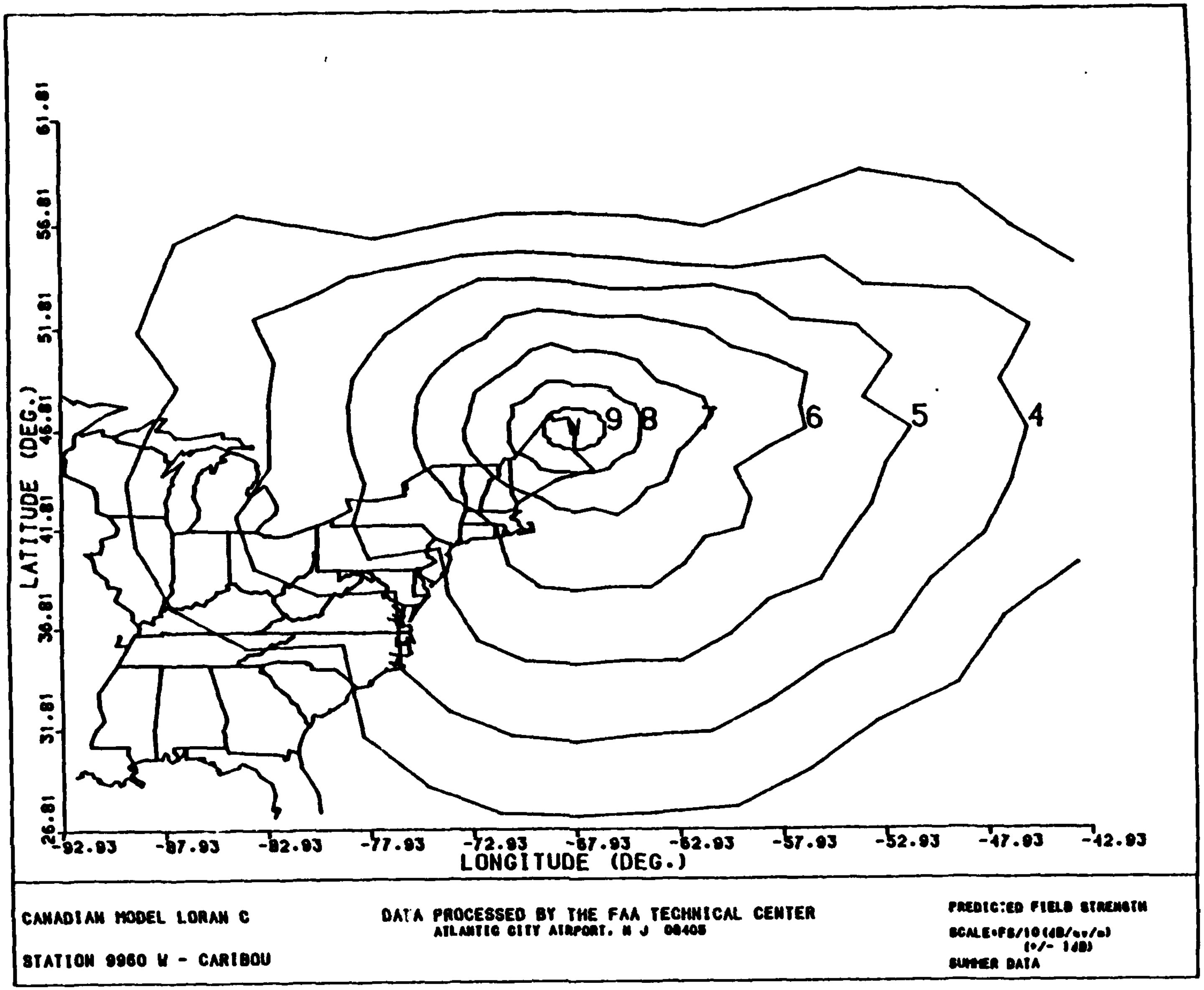


FIGURE C-2. PREDICTED FIELD STRENGTH CONTOURS, CARIBOU STATION 9960 W

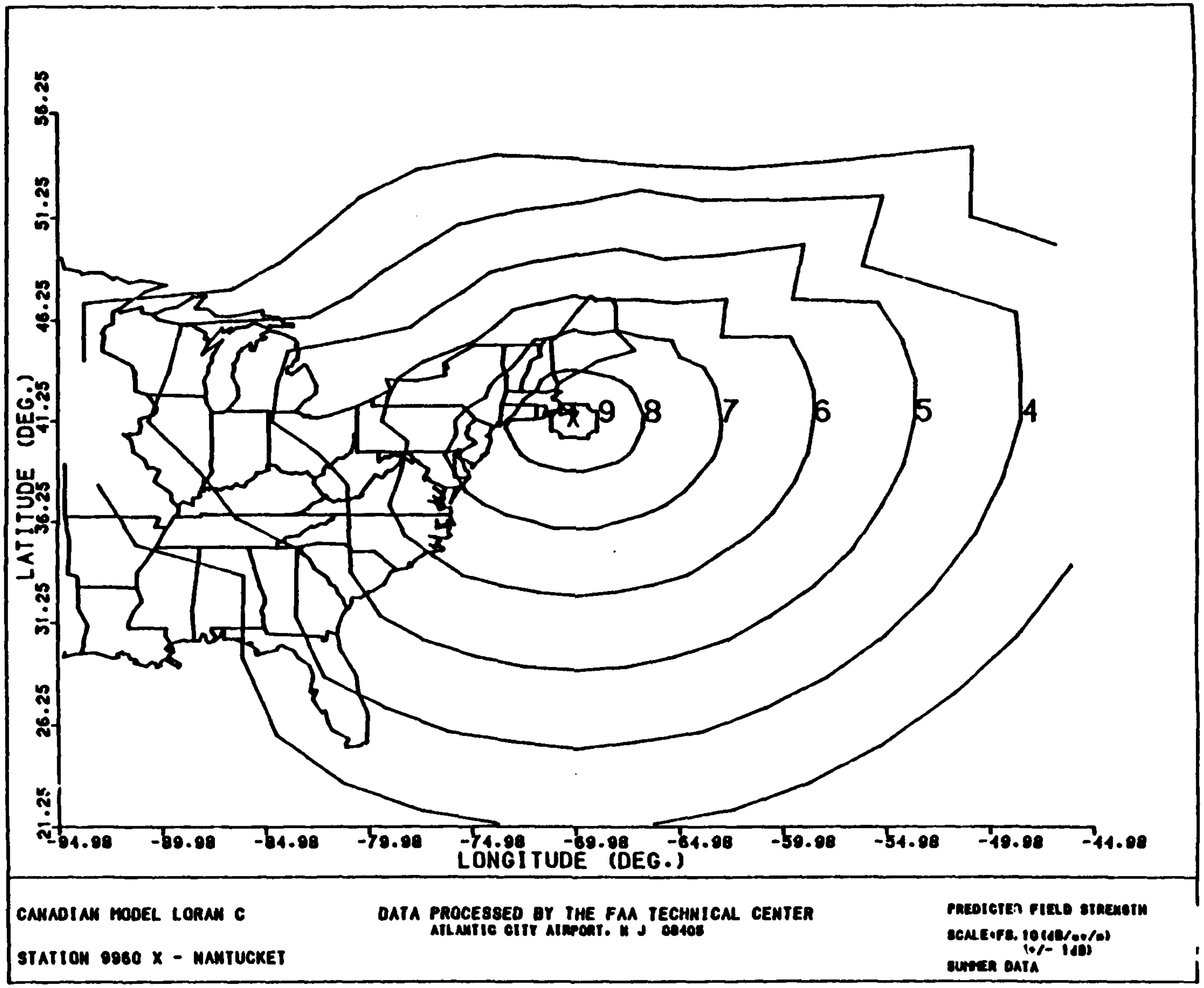


FIGURE C-3. PREDICTED FIELD STRENGTH CONTOURS, NANTUCKET STATION 9960 X

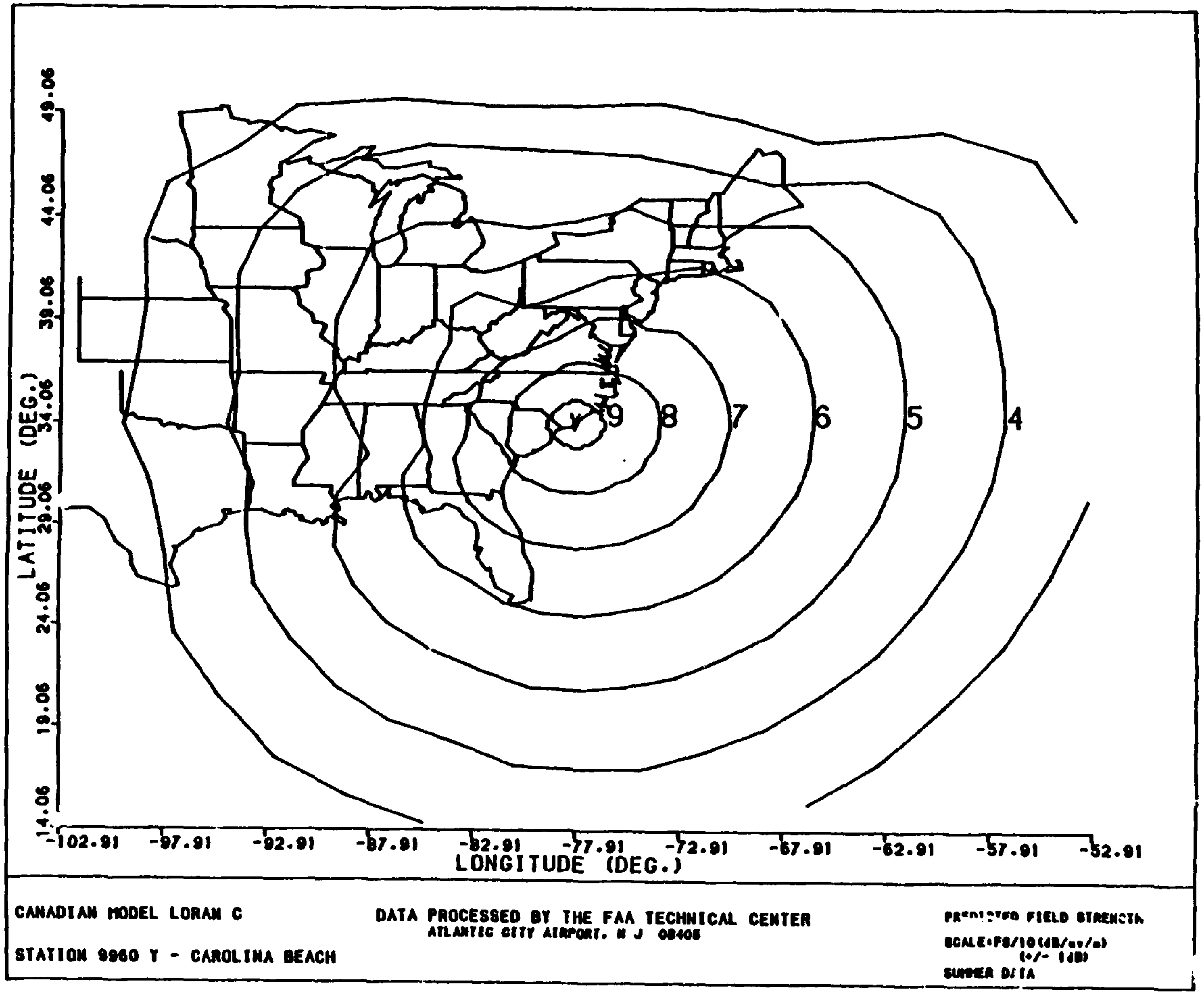


FIGURE C-4. PREDICTED FIELD STRENGTH CONTOURS, CAROLINA BEACH STATION 9960 Y

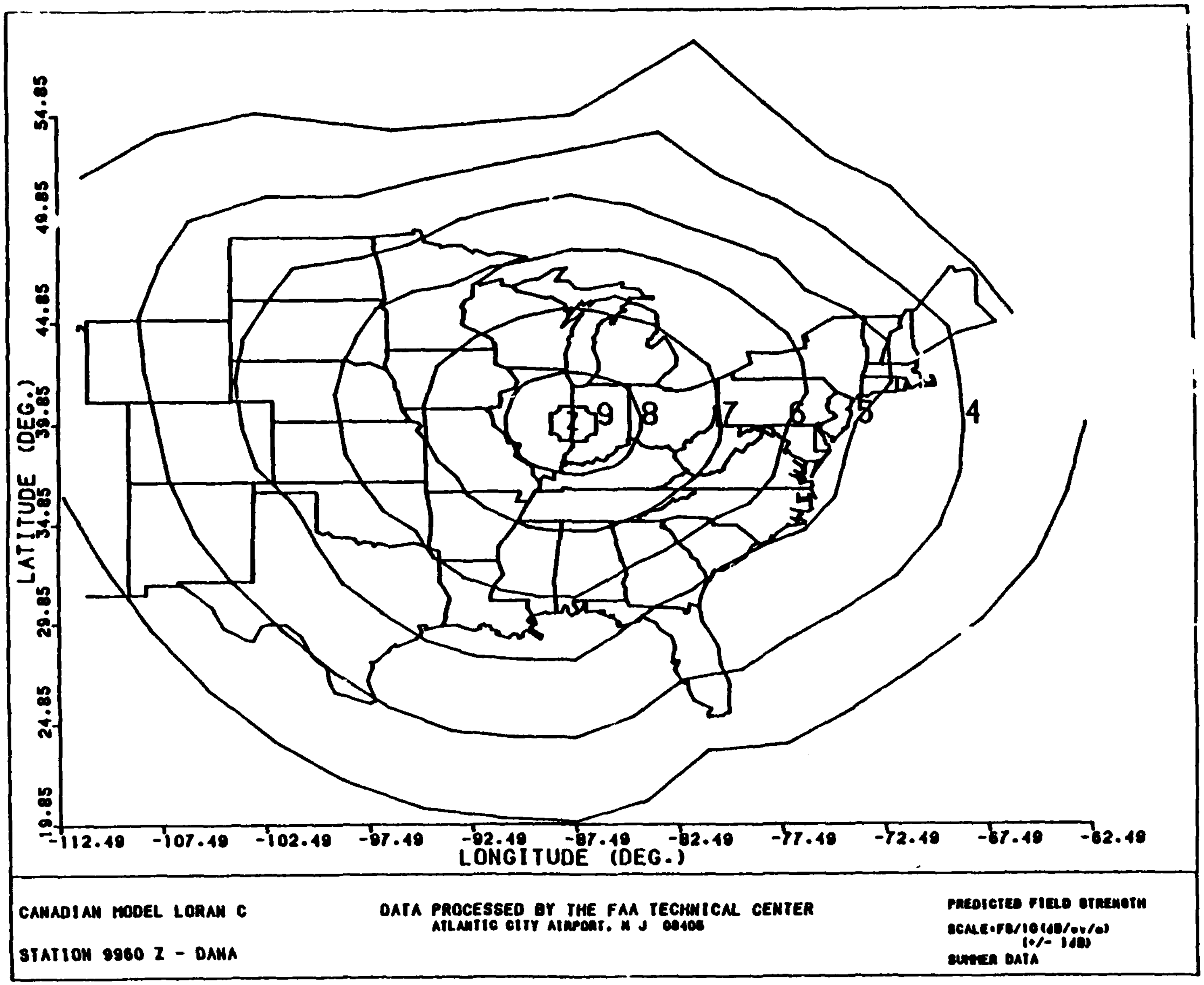


FIGURE C-5. PREDICTED FIELD STRENGTH CONTOURS, DANA STATION 9960 Z

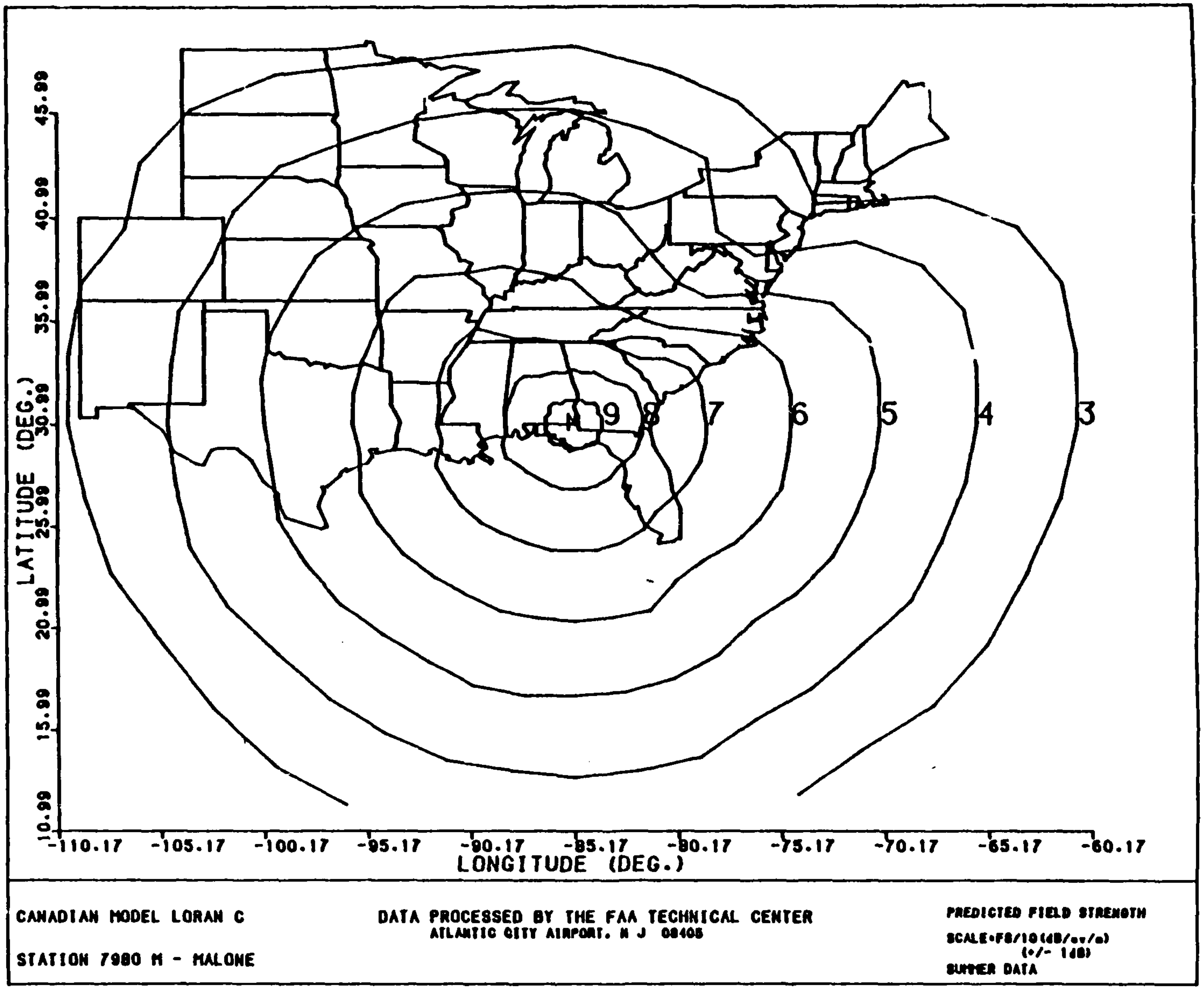


FIGURE C-6. PREDICTED FIELD STRENGTH CONTOURS, MALONE STATION 7980 M

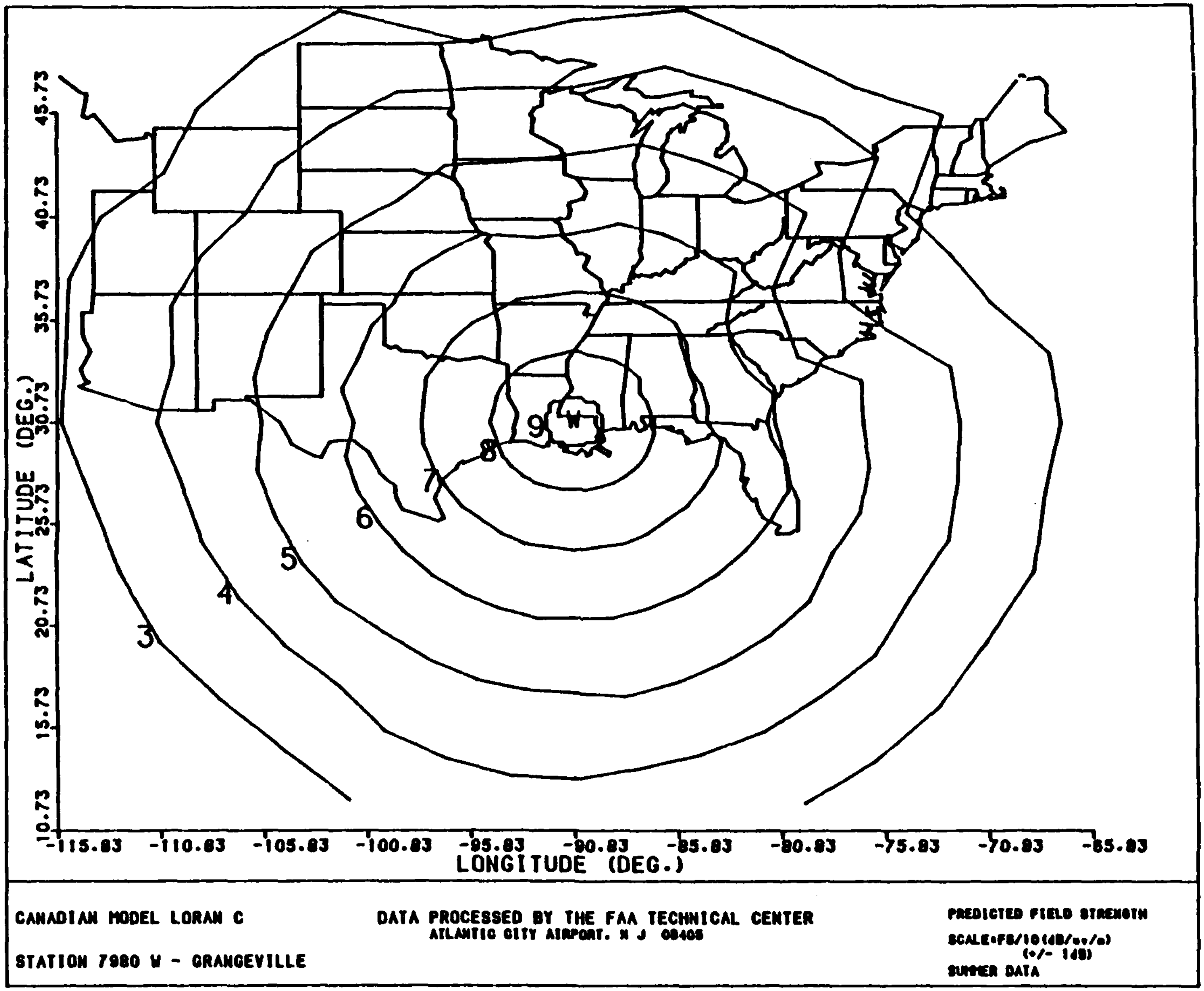


FIGURE C-7. PREDICTED FIELD STRENGTH CONTOURS, GRANGEVILLE STATION 7980 W

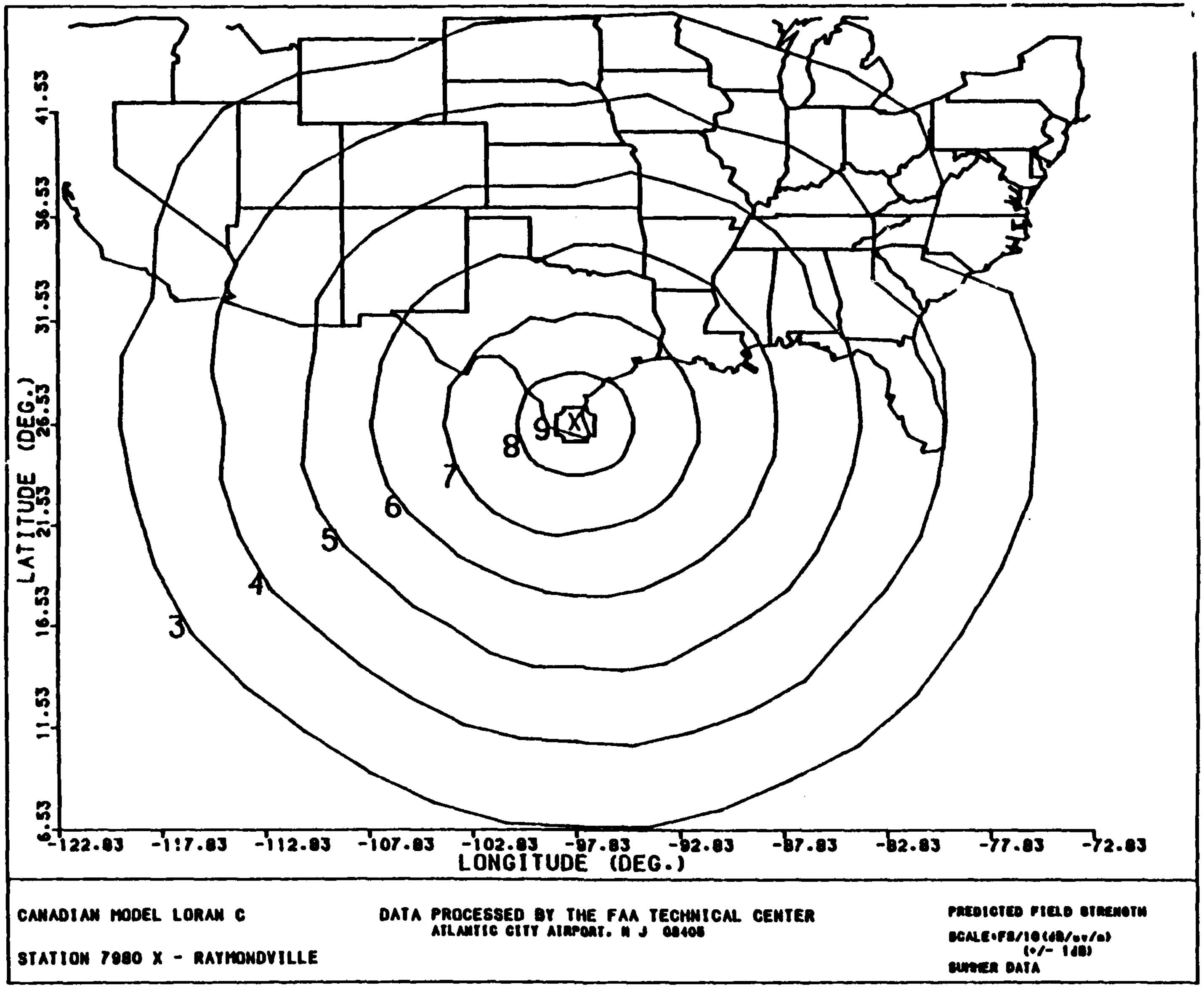


FIGURE C-8. PREDICTED FIELD STRENGTH CONTOURS, RAYMONDVILLE STATIO' 7980 X

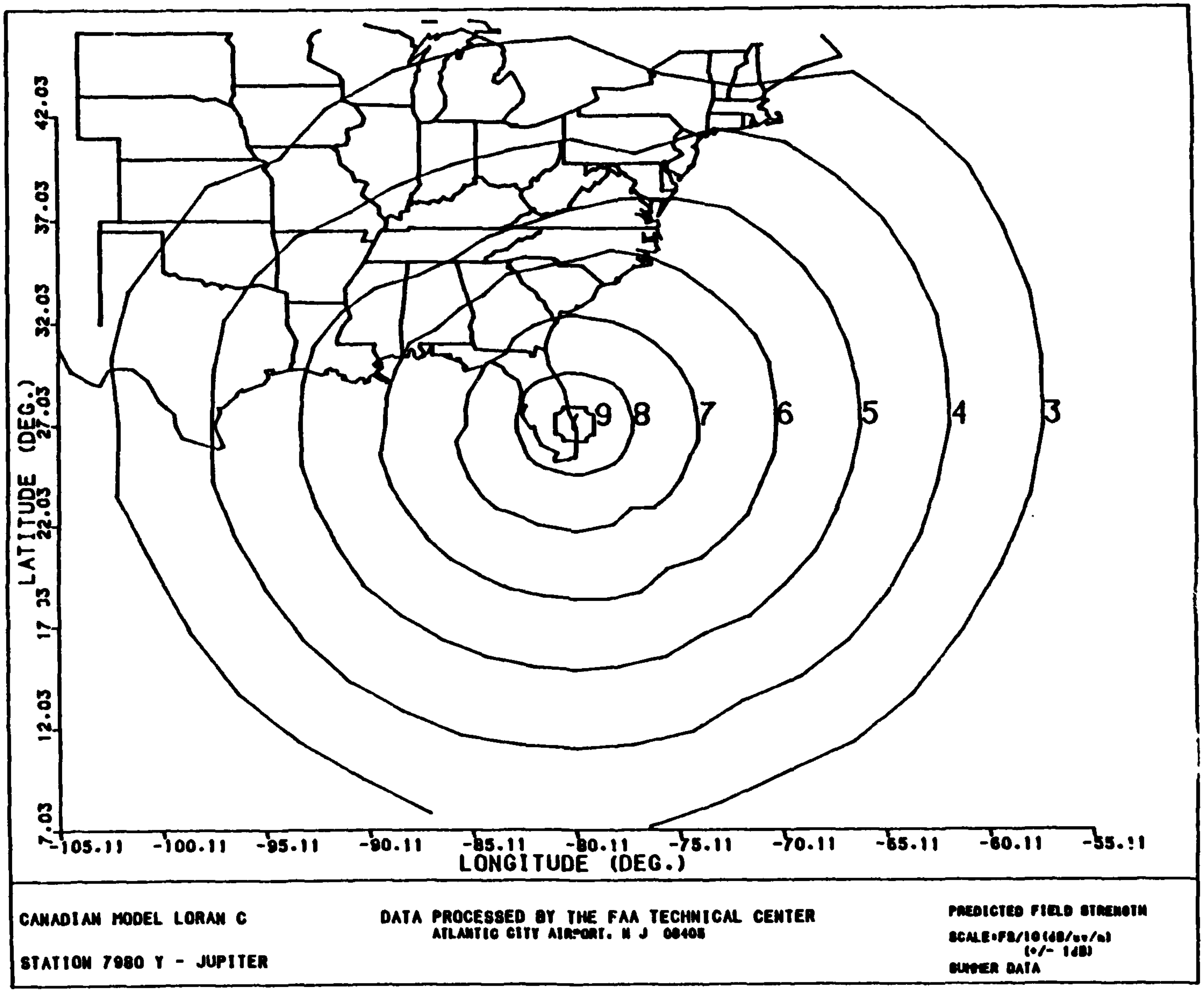


FIGURE C-9. PREDICTED FIELD STRENGTH CONTOURS, JUPITER STATION 7980 Y

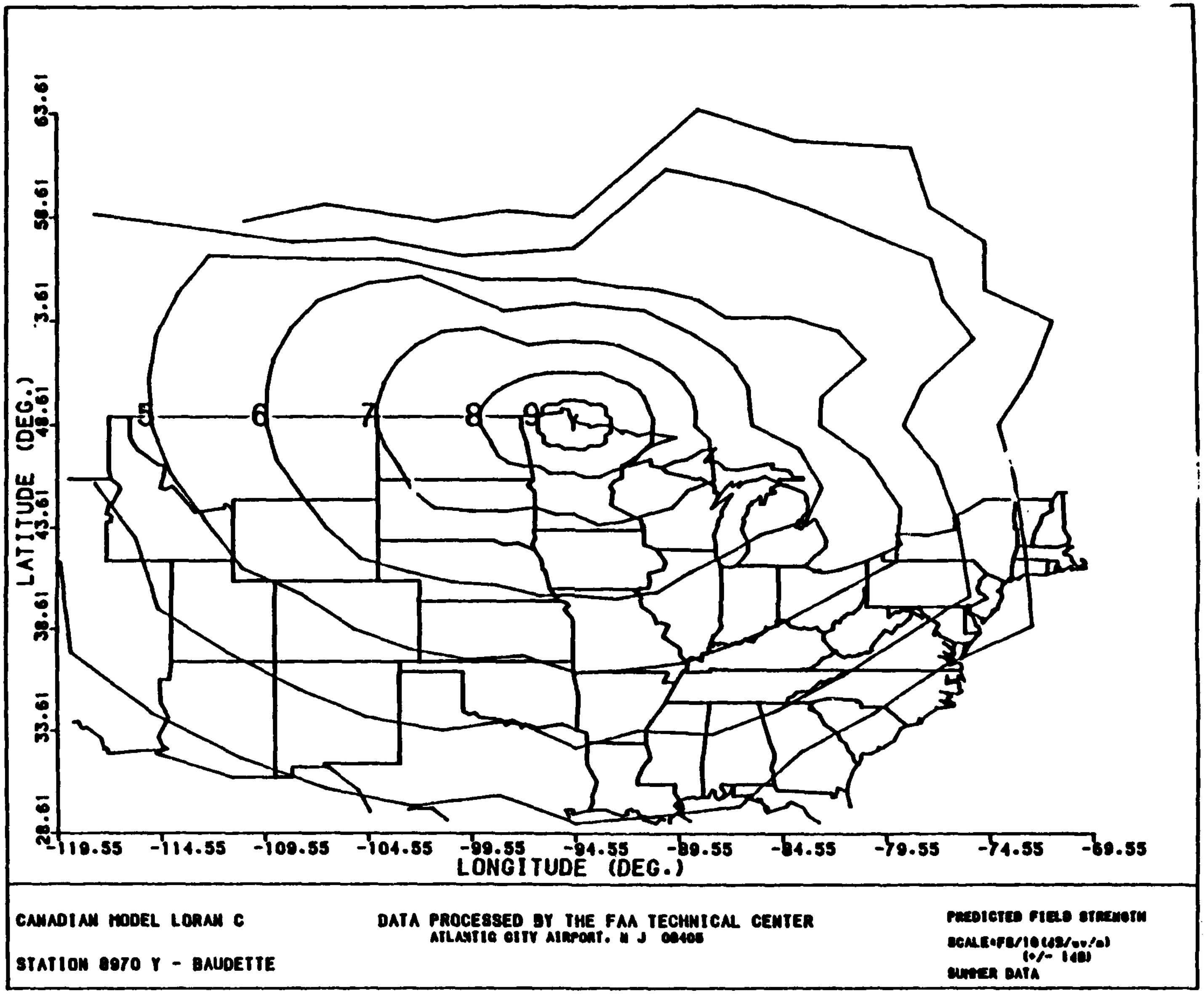
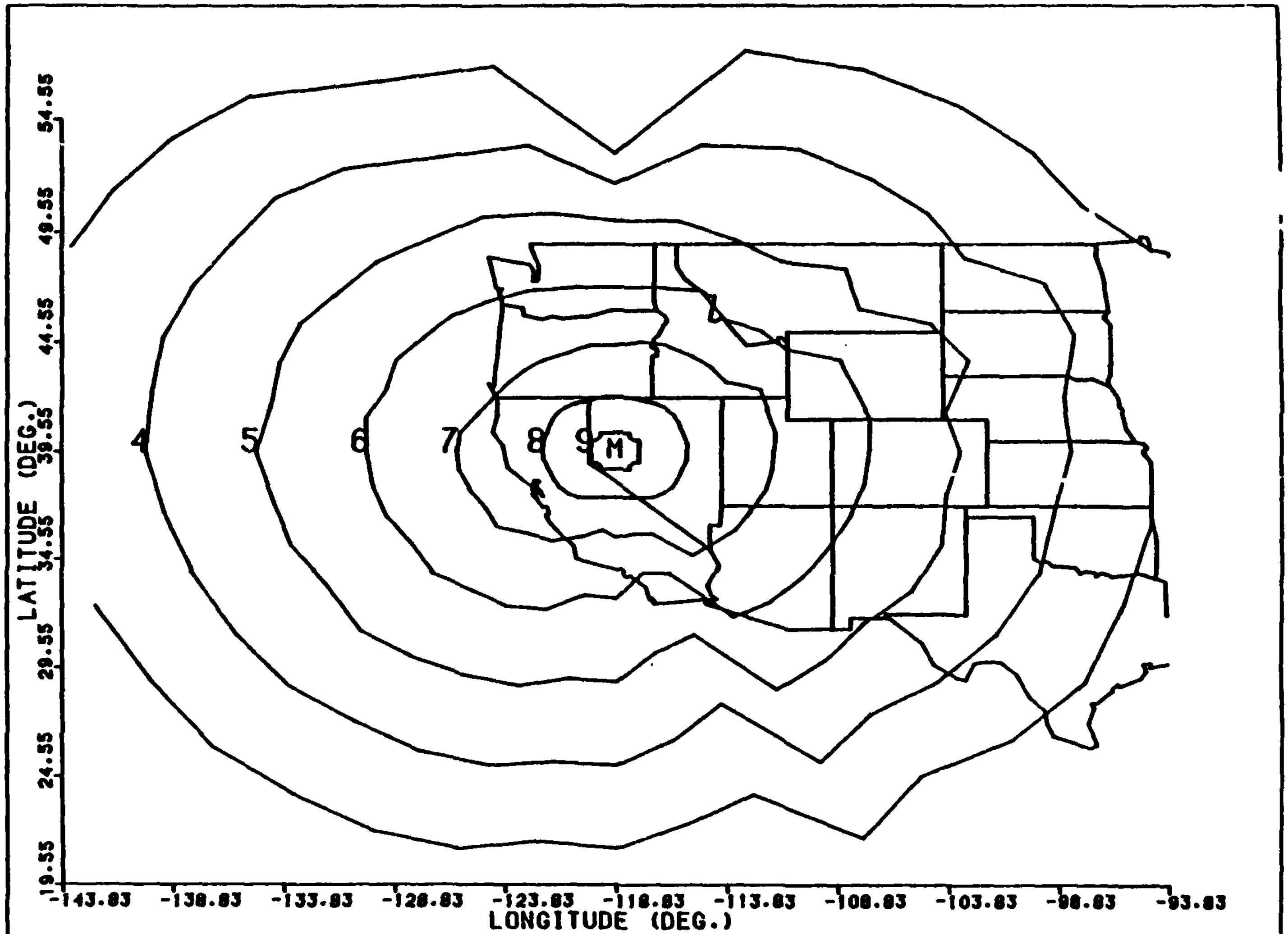


FIGURE C-10. PREDICTED FIELD STRENGTH CONTOURS, BAUDETTE STATION 8970 Y



CANADIAN MODEL LORAN C

STATION 9940 M - FALLON

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

PREDICTED FIELD STRENGTH
SCALE=FS/10(dB/uv/m)
(+/- 1dB)
SUMMER DATA

FIGURE C-11. PREDICTED FIELD STRENGTH CONTOURS, FALLON STATION 9940 M

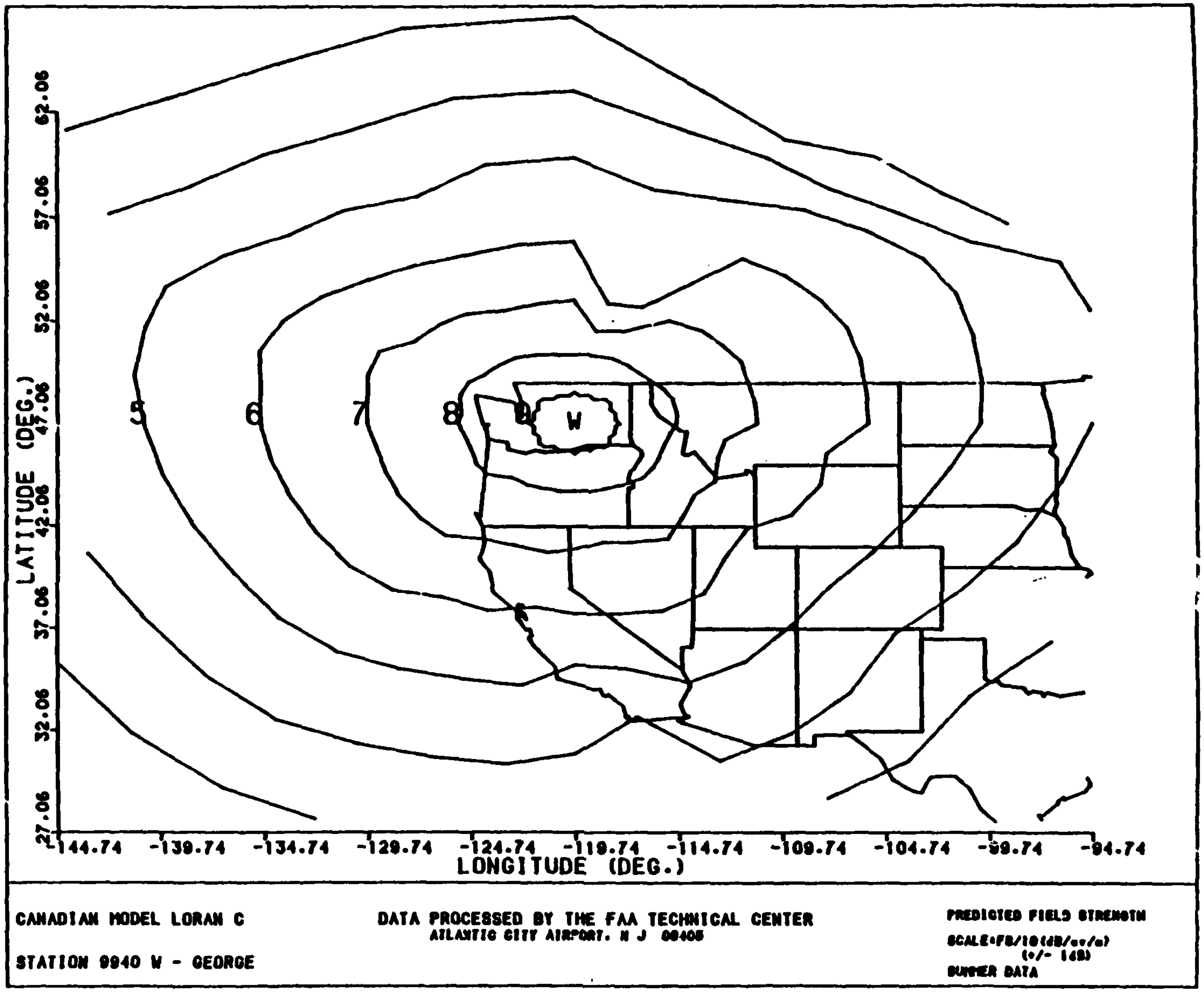


FIGURE C-12. PREDICTED FIELD STRENGTH CONTOURS, GEORGE STATION 9940 W

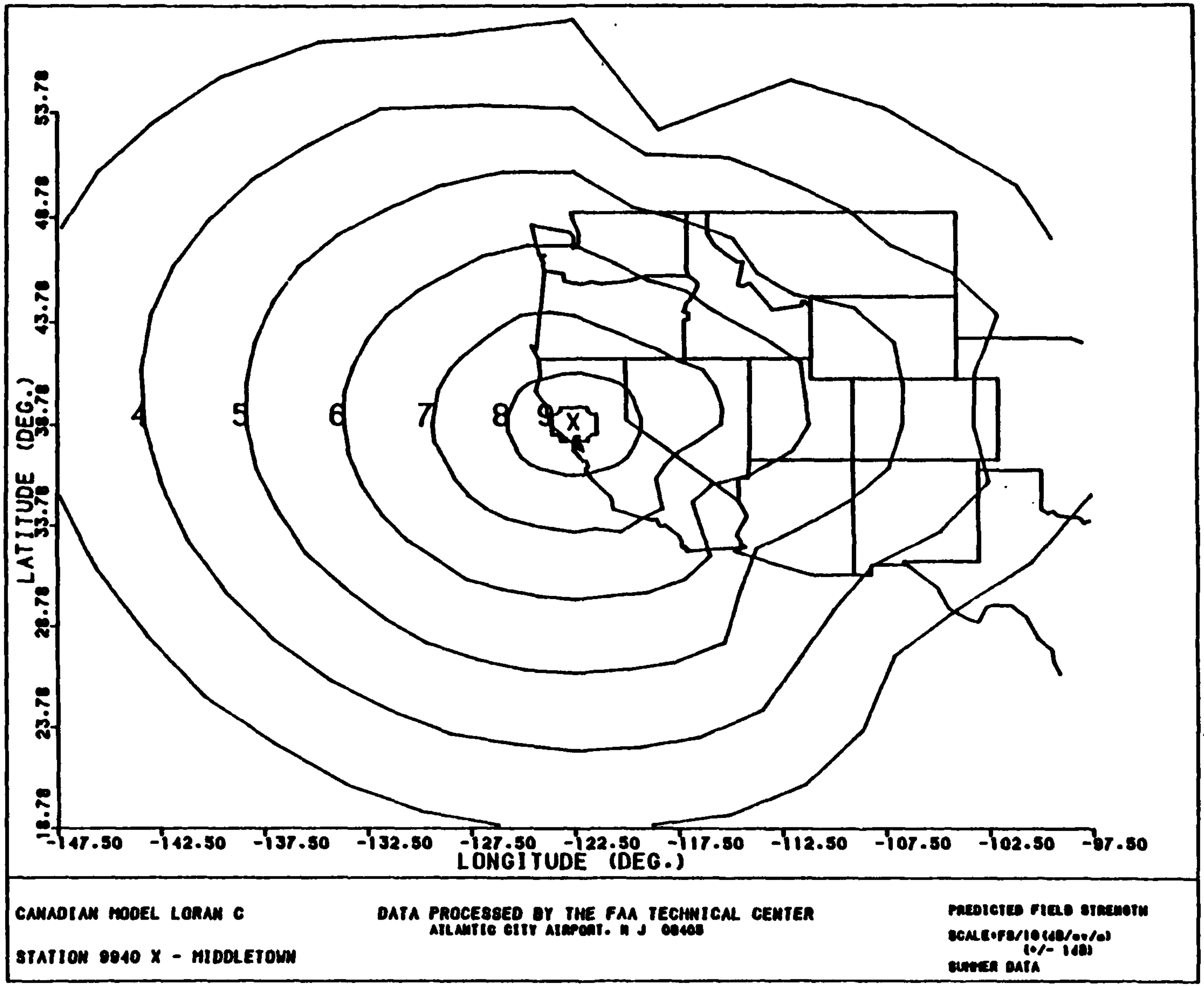


FIGURE C-13. PREDICTED FIELD STRENGTH CONTOURS, MIDDLETOWN STATION 9940 X

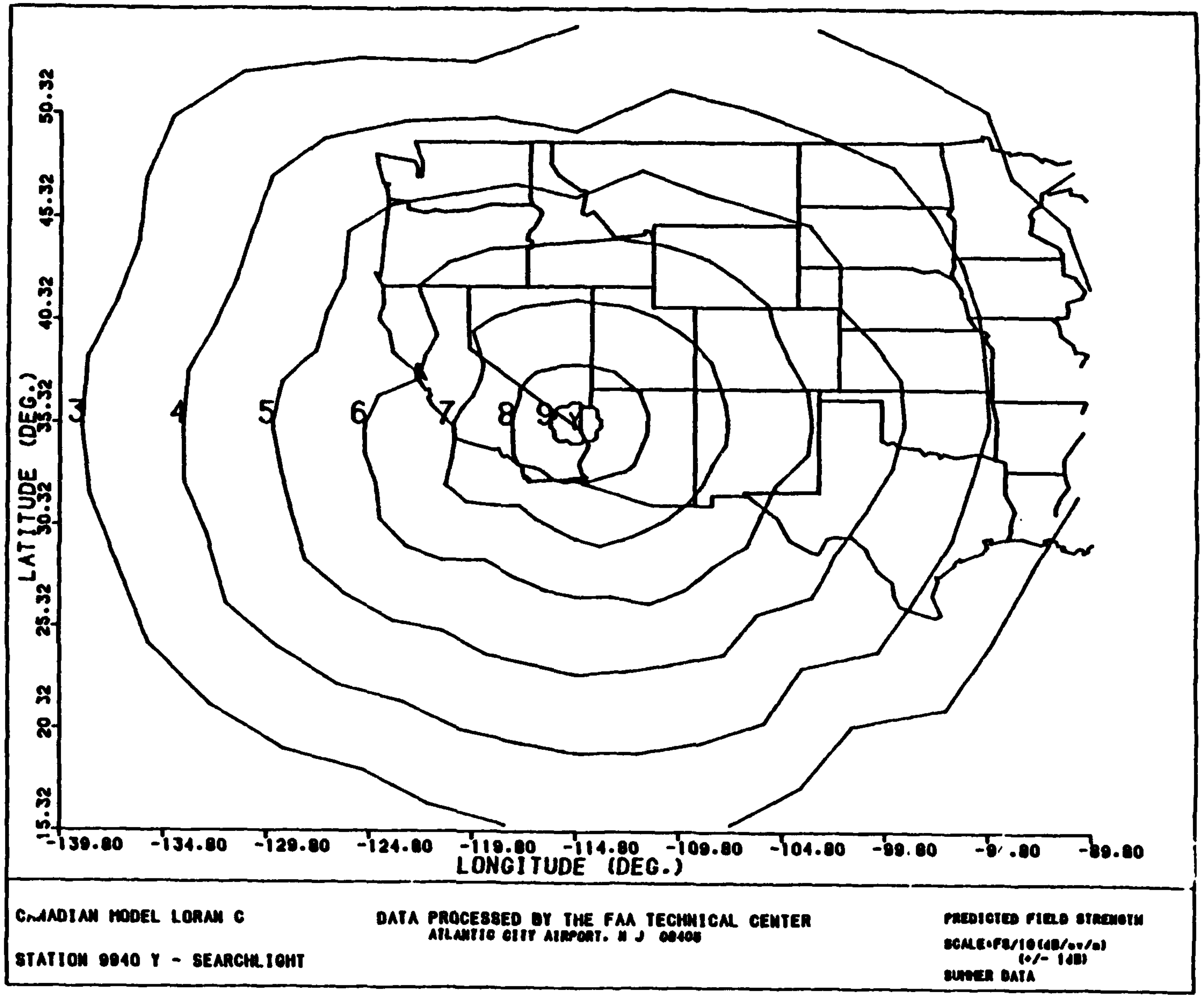


FIGURE C-14. PREDICTED FIELD STRENGTH CONTOURS, SEARCHLIGHT STATION 9940 Y

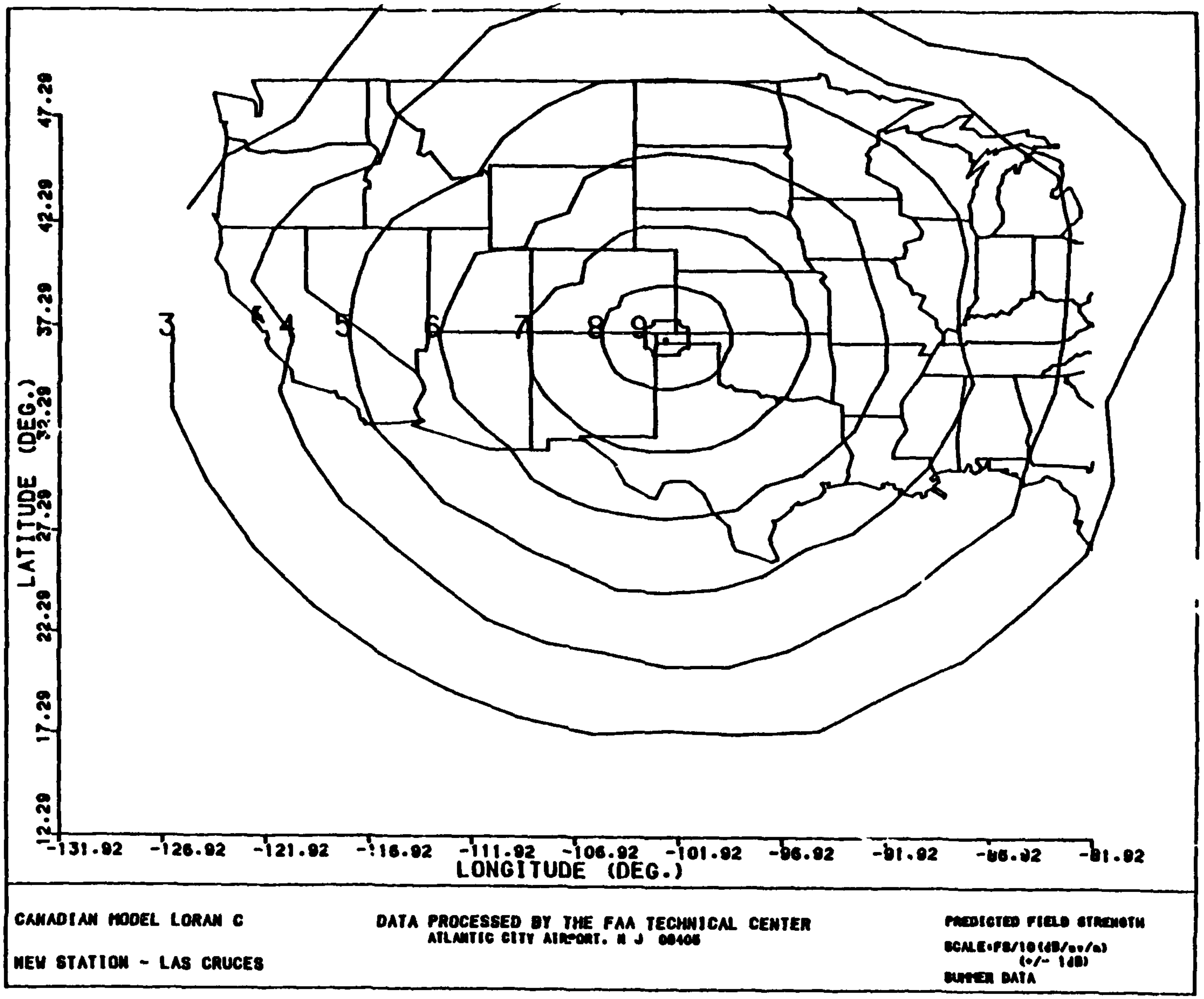


FIGURE C-15. PREDICTED FIELD STRENGTH CONTOURS, NEW STATION (LAS CRUCES)

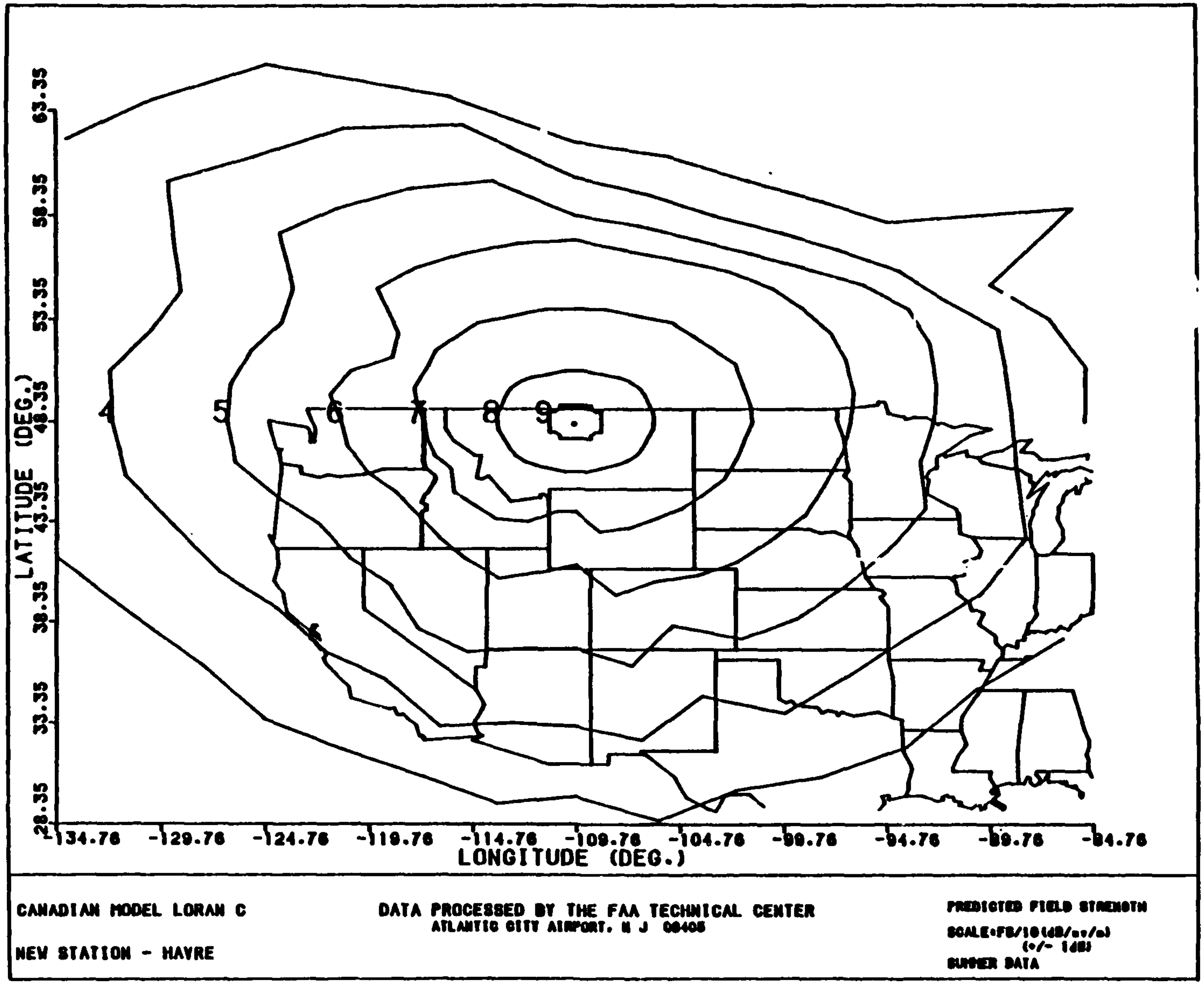


FIGURE C-16. PREDICTED FIELD STRENGTH CONTOURS, NEW STATION (HAVRE)

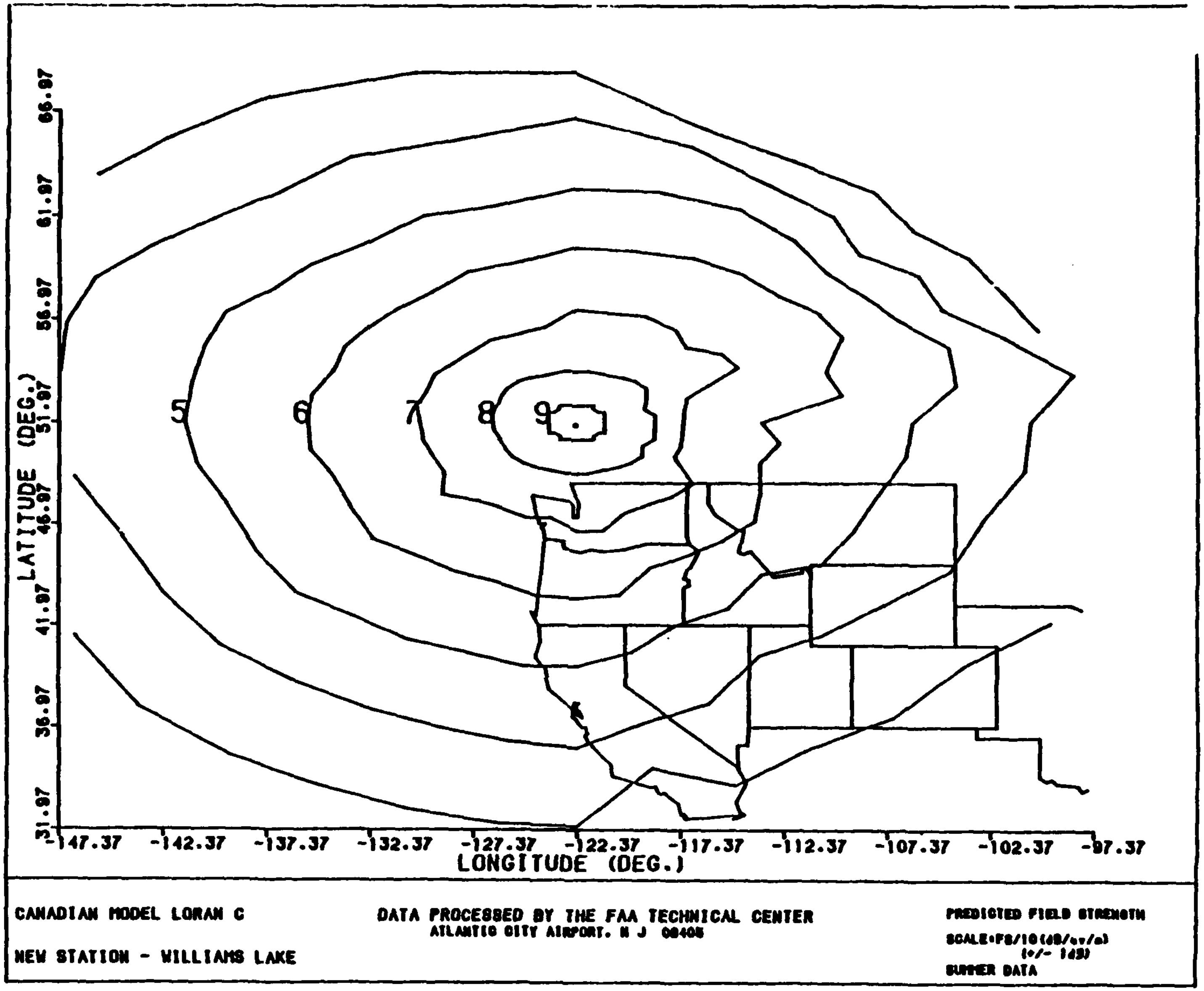


FIGURE C-17. PREDICTED FIELD STRENGTH CONTOURS, NEW STATION (WILLIAMS LAKE)

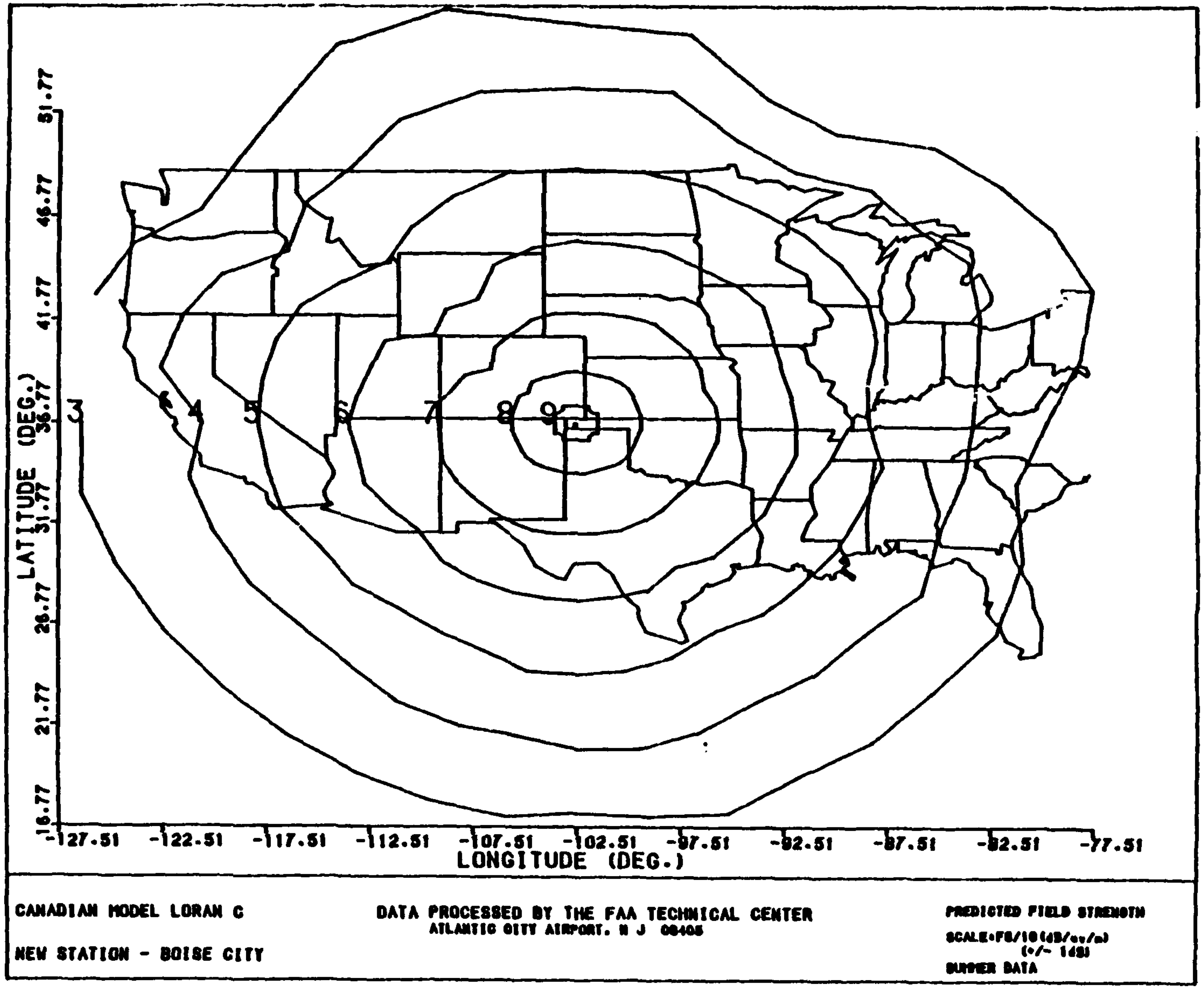


FIGURE C-18. PREDICTED FIELD STRENGTH CONTOURS, NEW STATION (BOISE CITY)

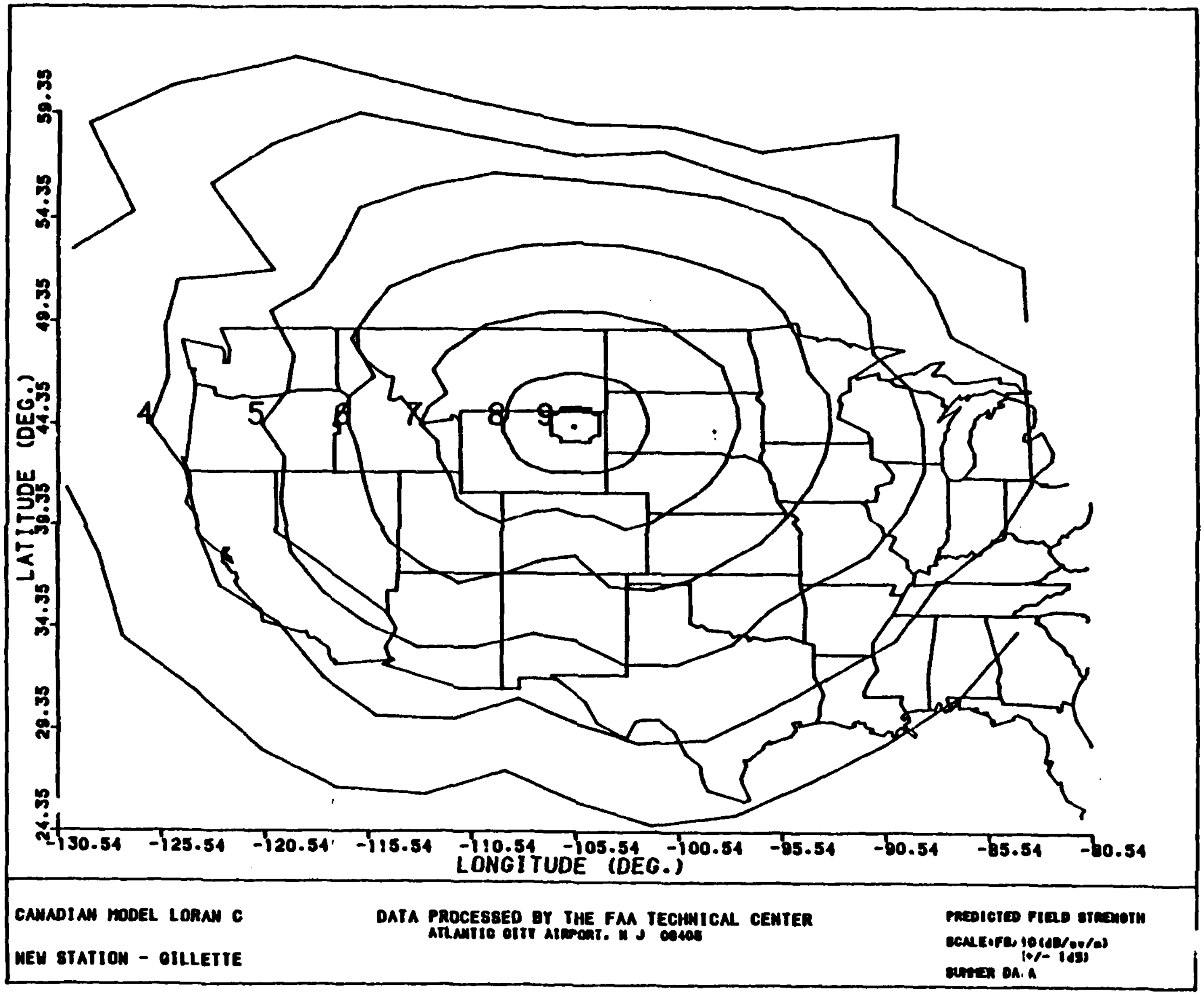


FIGURE C-19. PREDICTED FIELD STRENGTH CONTOURS, NEW STATION (GILLETTE)

APPENDIX D

ATMOSPHERIC NOISE PLOTS

LIST OF ILLUSTRATIONS

There are two sets of plots in this appendix. Figures D-1 and D-4 show atmospheric noise contours of the contiguous United States (CONUS) as predicted by the Canadian Loran C model. Figures D-2 and D-3 show plots of atmospheric noise values along the Federal Aviation Administration (FAA) Technical Center's flightpath. The numbers on the plot are a multiple of 10 decibels (dB) per microvolt per meter (dB/µV/m) +/- 1 dB and represent summer data.

In figure D-1, atmospheric noise contours result from the original noise data base received with the Canadian software. The Canadian model documentation seems to indicate that the values generated for noise were based on "World Distribution and Characteristics of Atmospheric Radio Noise 85," distributed by the International Radio Consultative Committee (CCIR). The model calculates a value of noise that is expected to be exceeded only 5 percent of the time. CCIR noise data utilized was from the summertime average for June, July, and August. The noise parameters from the CCIR were corrected for a frequency of 100 kilohertz (kHz) and bandwidth of 30 kHz for summertime.

As reported in a previous technical note (reference 5), the values shown in figure D-1 do not correlate well with predicted noise data used by the United States Coast Guard (USCG) or Federal Aviation Administration (FAA) Technical Center flight measured noise data. Figure D-2 shows the same data as figure D-1 but plots it along the FAA Technical Center's Loran C stability flightpath. For comparison, figure D-3 is atmospheric noise data measured during flight tests of the CONUS. When compared with figure D-2, it can be seen that the original Canadian software employed noise values significantly greater than flight measured values.

Figure D-4 is a result of comparisons made between model data, flight measured data and USCG predicted noise data. As detailed in the above mentioned technical note, a 15-percent reduction of Canadian model predicted noise data through parts of the CONUS was necessary to make the model more realistic.

Canadian model noise data employed for the east, mid-west and west coast compared well with flight measured data and USCG predicted data. Values utilized for the central CONUS and southeast were very high. These values ranged from 60 dB/µV/m to 72 dB/µV/m. A graduated reduction of noise values for this area was made. For every 1 dB/µV/m above 60 dB/µV/m, the noise value employed by the model was reduced by a factor of 1.2 percent. Noise reduction graduated from 0 percent for 60 dB/µV/m values to 14.4 percent for 72 dB/µV/m. As an example, a 62 dB/µV/m value was reduced to 60.5; a 70 dB/µV/m value was reduced to 61.6 dB/µV/m.

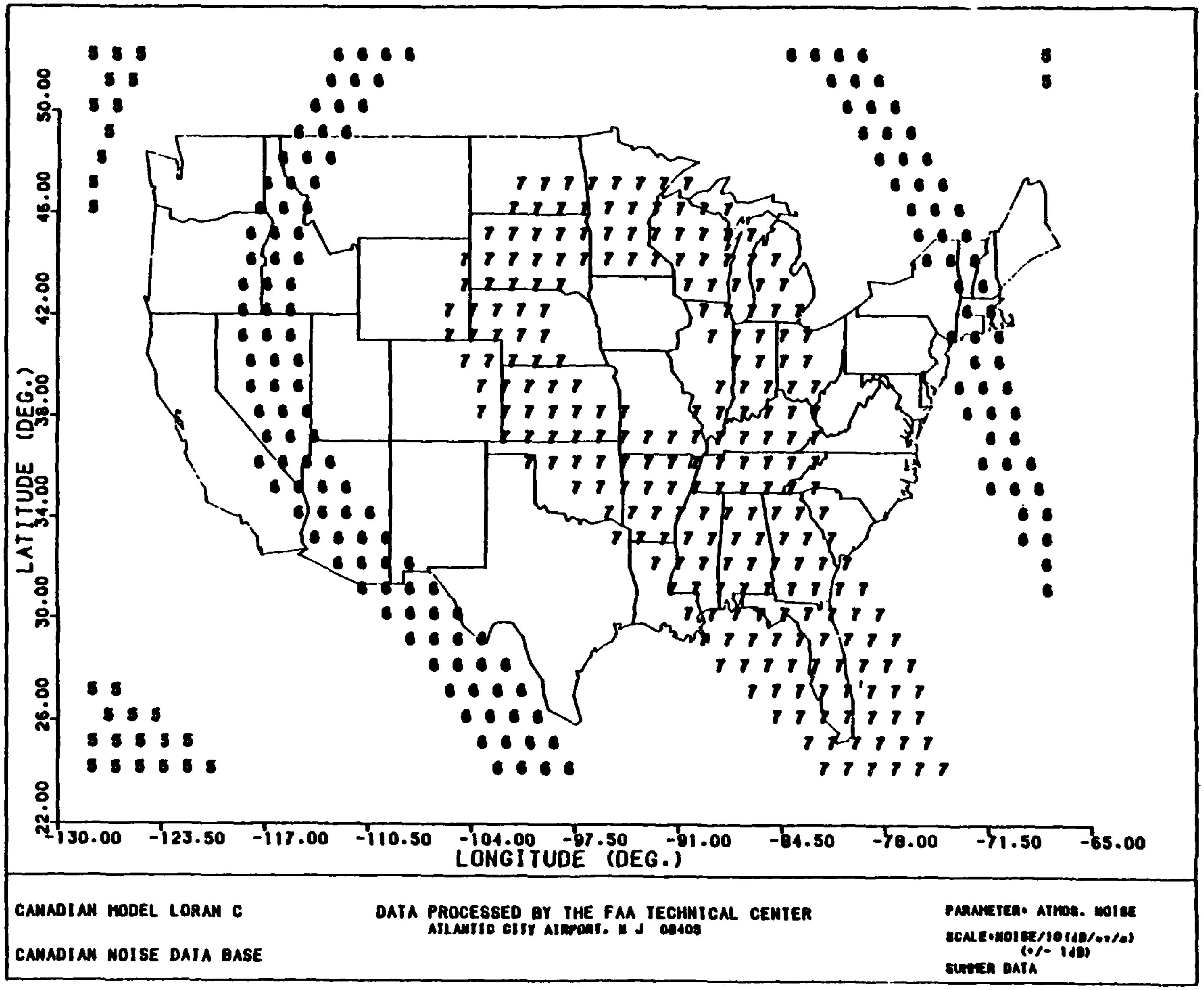


FIGURE D-1. ATMOSPHERIC NOISE CONTOUR (CANADIAN NOISE DATA BASE)

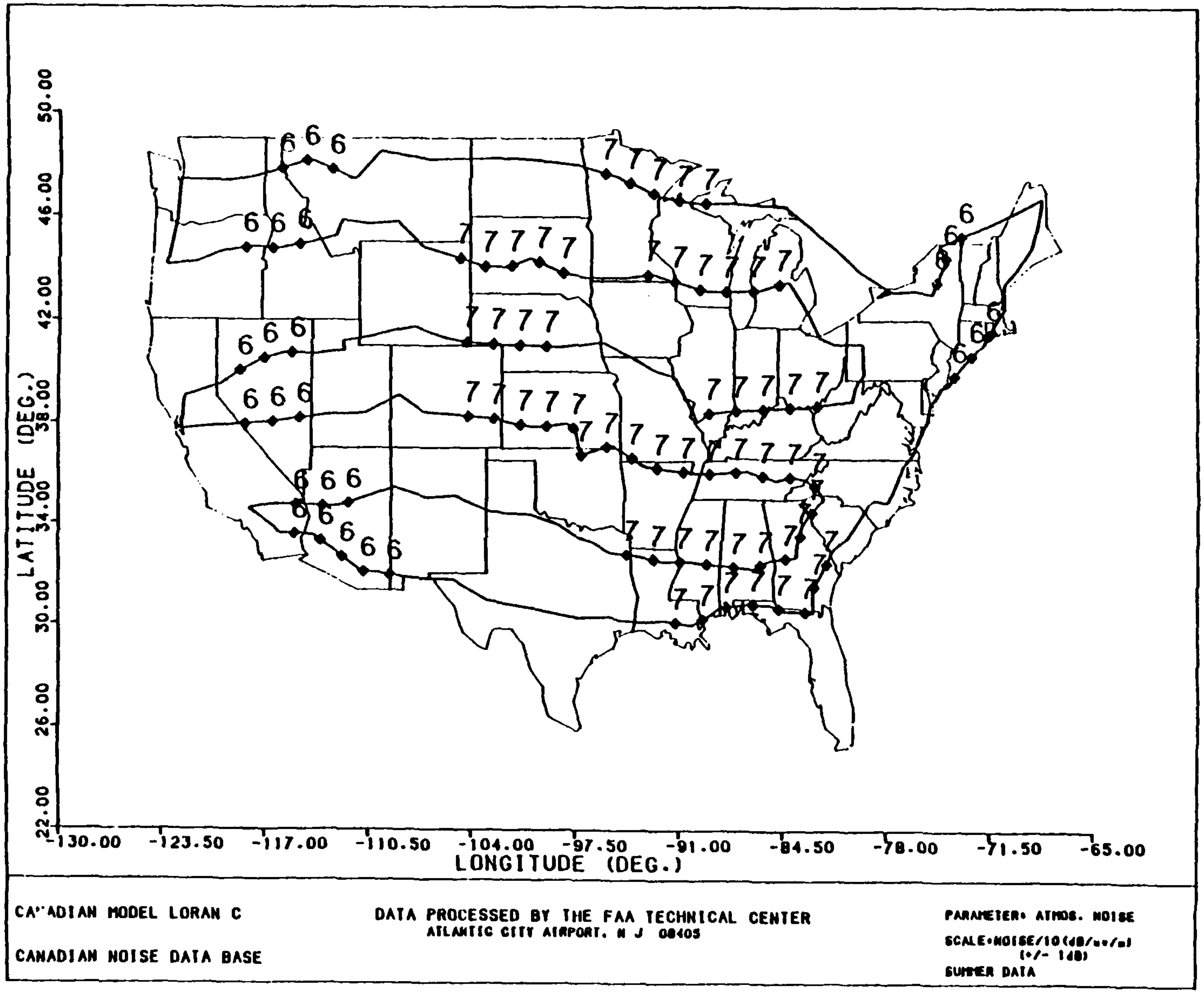


FIGURE D-2. ATMOSPHERIC NOISE ALONG THE FLIGHTPATH (CANADIAN NOISE DATA BASE)

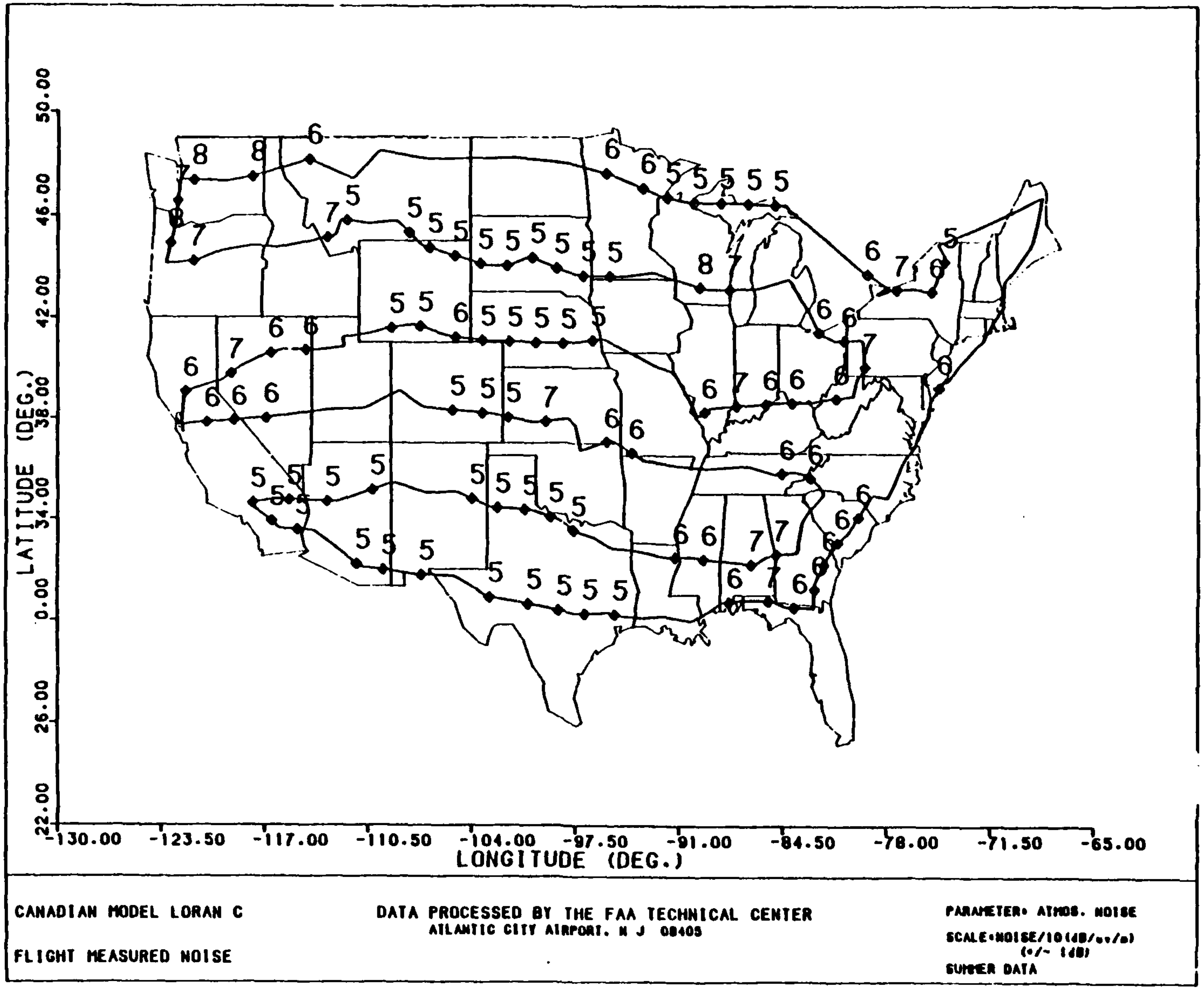


FIGURE D-3. ATMOSPHERIC NOISE ALONG THE FLIGHTPATH (FLIGHT MEASURED VALUES)

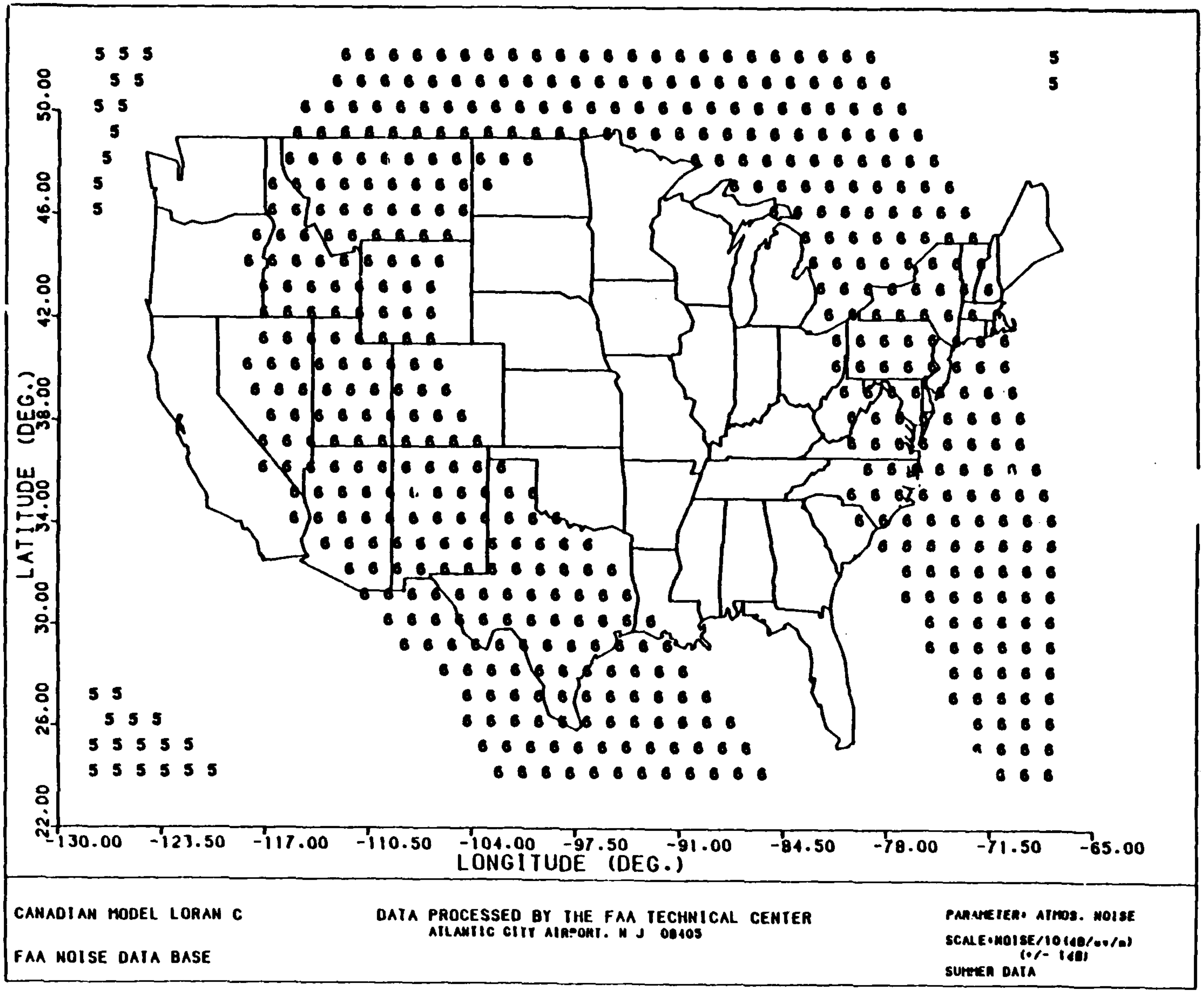


FIGURE D-4. ATMOSPHERIC NOISE CONTOUR (CANADIAN NOISE DATA BASE *REVISED* BY THE FAA TECHNICAL CENTER)

APPENDIX E

LORAN C COVERAGE CONTOUR PLOTS

LIST OF ILLUSTRATIONS

The plots of this appendix show the contiguous United States (CONUS) coverage contours predicted by the Canadian Loran C propagation model. There are two sets of coverage contours. One set, figures E-1 to E-8 predict coverage using the Federal Aviation Administration (FAA) Technical Center's improved version of the model. The second set, figures E-9 to E-15, show coverage contours based on the Canadian software as it was delivered to the FAA Technical Center. Both sets of plots reflect threshold limits of 1500 feet for probable fix accuracy of two times distance root mean square (2DRMS) and -10 dB/μV/m for signal to noise ratio (SNR).

Figure E-1 is a plot which shows the CONUS predicted coverage without the new central chains. The coverage contour was produced by using atmospheric noise and conductivity data bases which were improved by the FAA Technical Center. Validation of these modifications were demonstrated in this and other reports (references 5 and 6). The improved model predicts coverage comparable to the United States Coast Guard (USCG).

Figure E-2 shows the CONUS predicted coverage when the new central chains are placed in service. The plots in figures E-3 through E-8 are predicted coverage contours of the indicated Loran C chain. These plots were made utilizing the FAA's improved data bases for noise and conductivity. Included are predicted Canadian model coverage contours of the new mid-west chains, North Central and South Central (figures E-7 and E-8).

Figure E-9 shows the CONUS predicted coverage using the atmospheric noise and conductivity data as delivered by the Canadians. The data employed by the original version of the model causes reduced coverage contours. Areas of known Loran C coverage are not shown in the plot. When compared with figure E-1, the coverage difference is noticeable. Coverage predicted by the original software was limited because of high atmospheric noise values and poor conductivity values utilized for particular areas of the CONUS.

Figures E-10 through E-15 are coverage plots of the indicated Loran C chain utilizing the original data bases delivered with the software. Each of these plots show reduced coverage contours for the same reason indicated above.

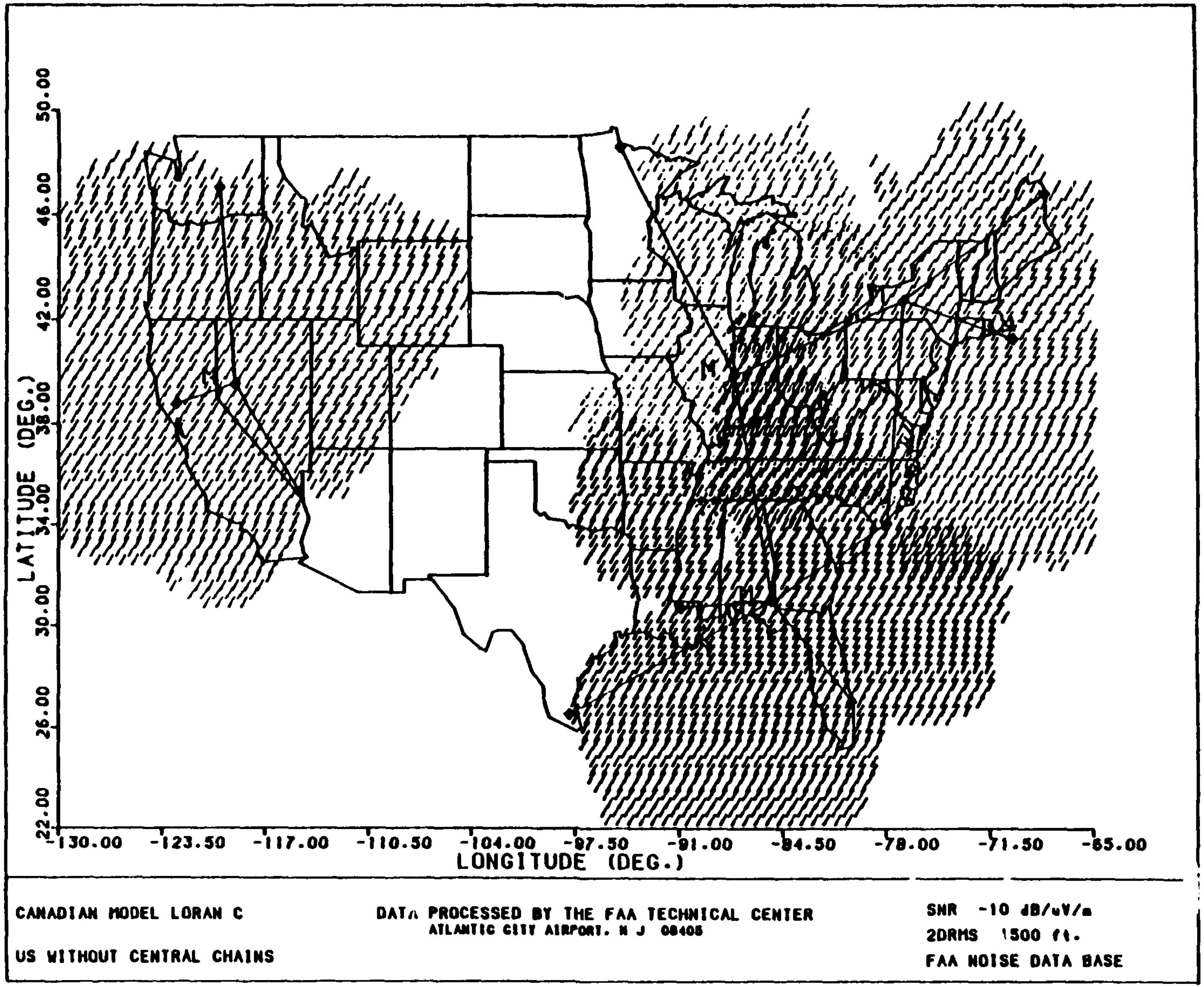


FIGURE E-1. PREDICTED U.S. LORAN C COVERAGE WITH FAA REVISED DATA BASES (WITHOUT NEW MID-CONTINENT CHAINS)

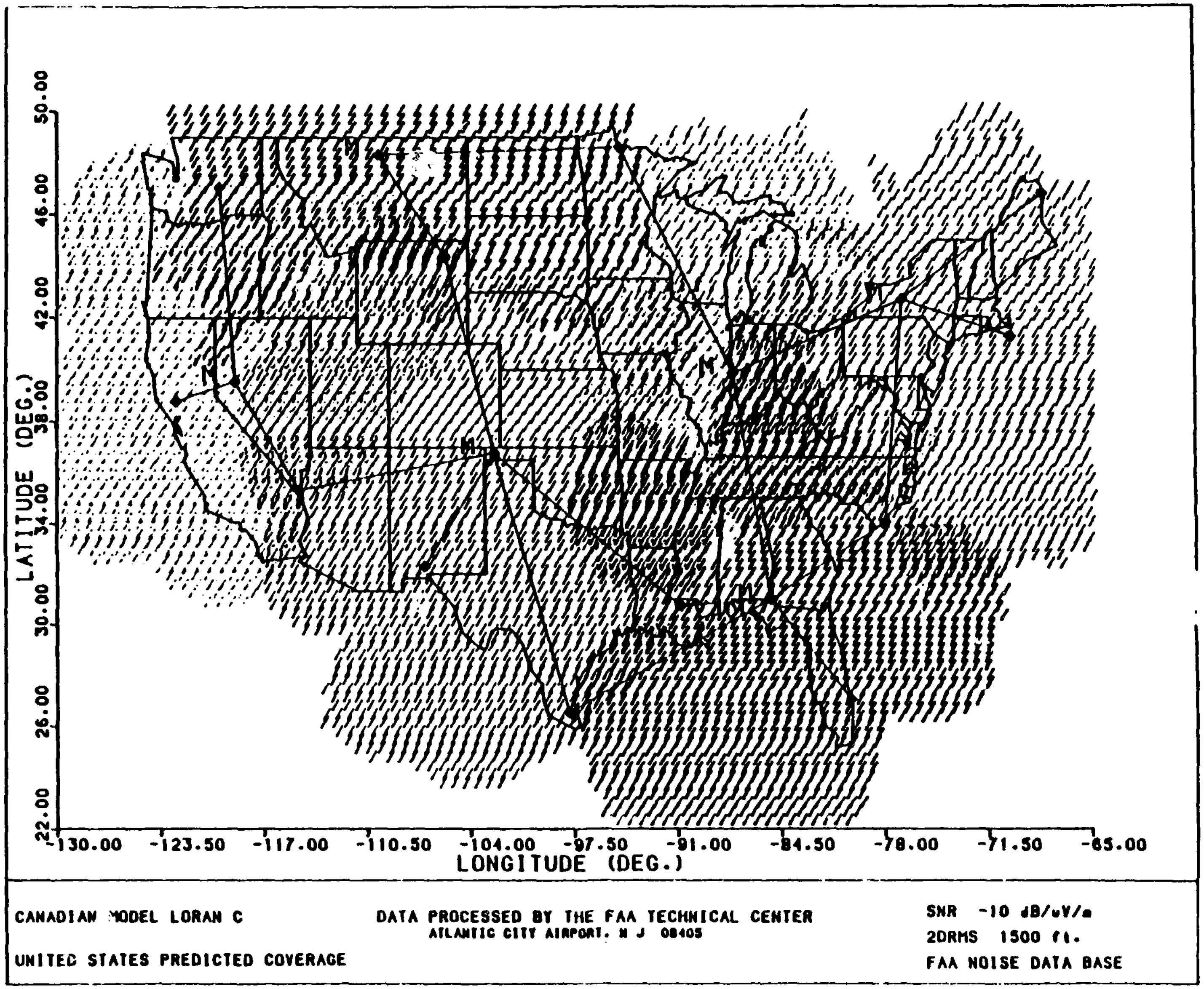


FIGURE E-2. PREDICTED U.S. LORAN C COVERAGE (WITH NEW MID-CONTINENT CHAINS)

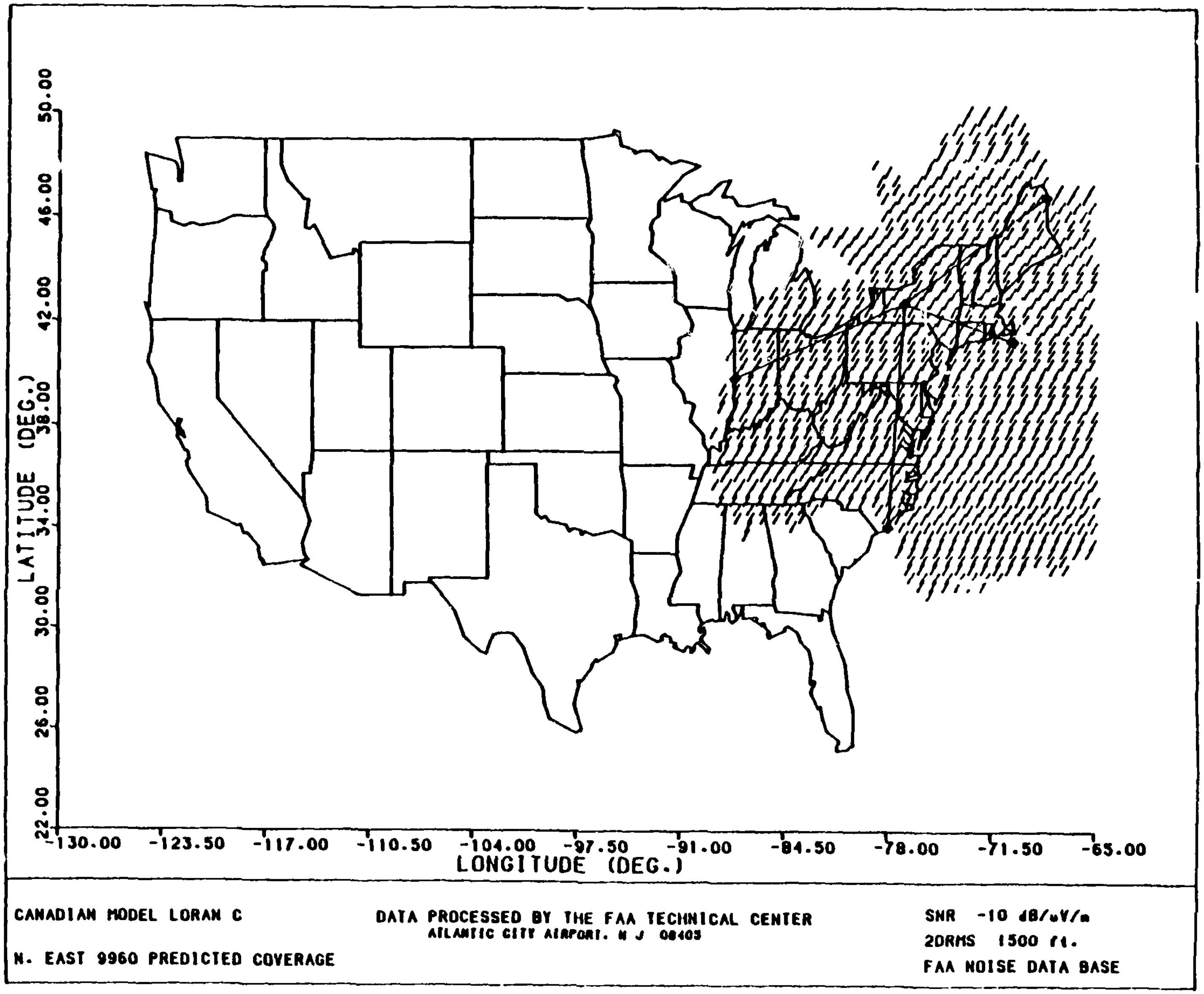


FIGURE E-3. PREDICTED LORAN C COVERAGE FOR THE 9960 CHAIN (FAA REVISED DATA BASES)

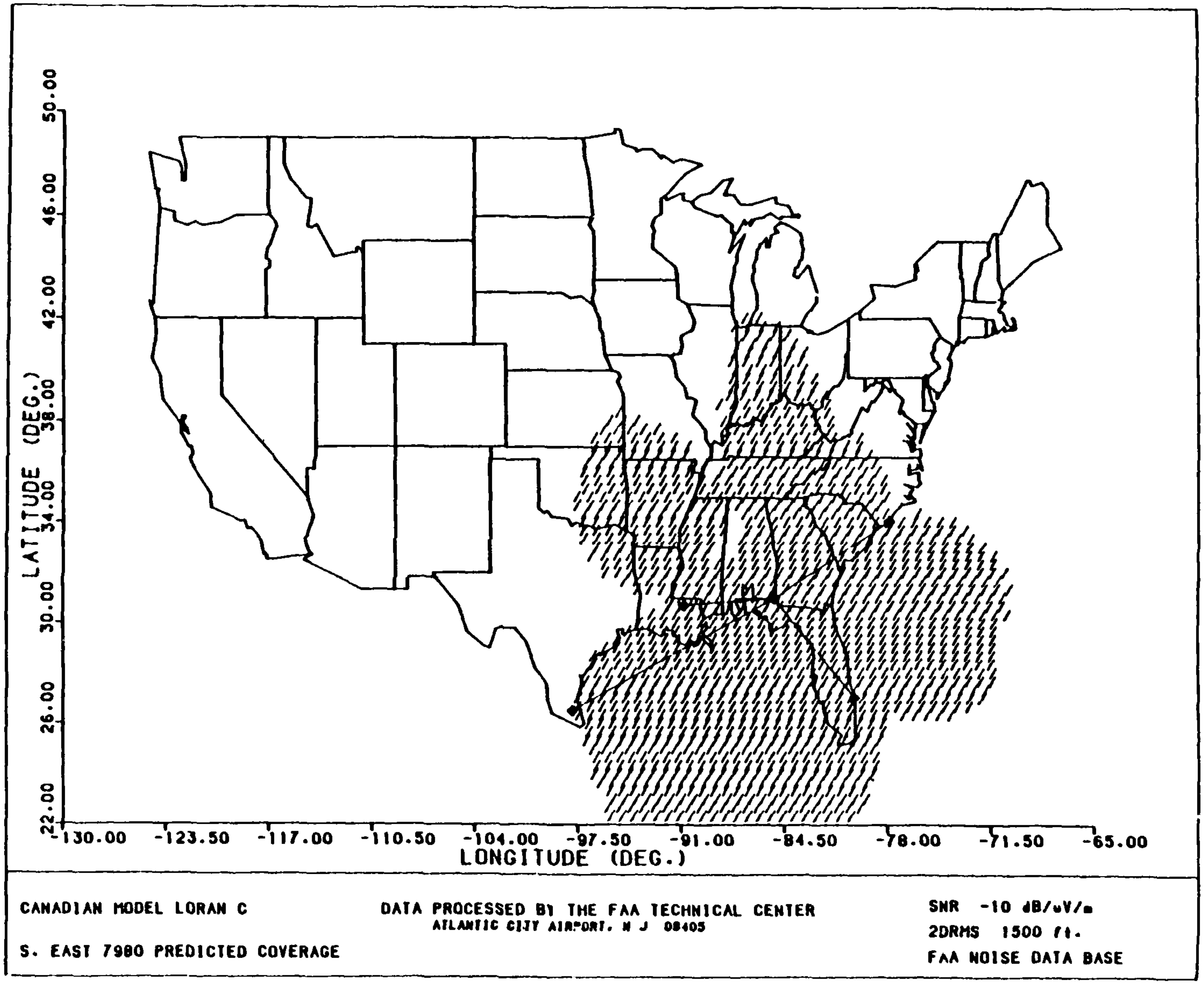


FIGURE E-4. PREDICTED LORAN C COVERAGE FOR THE 7980 CHAIN (FAA REVISED DATA BASES)

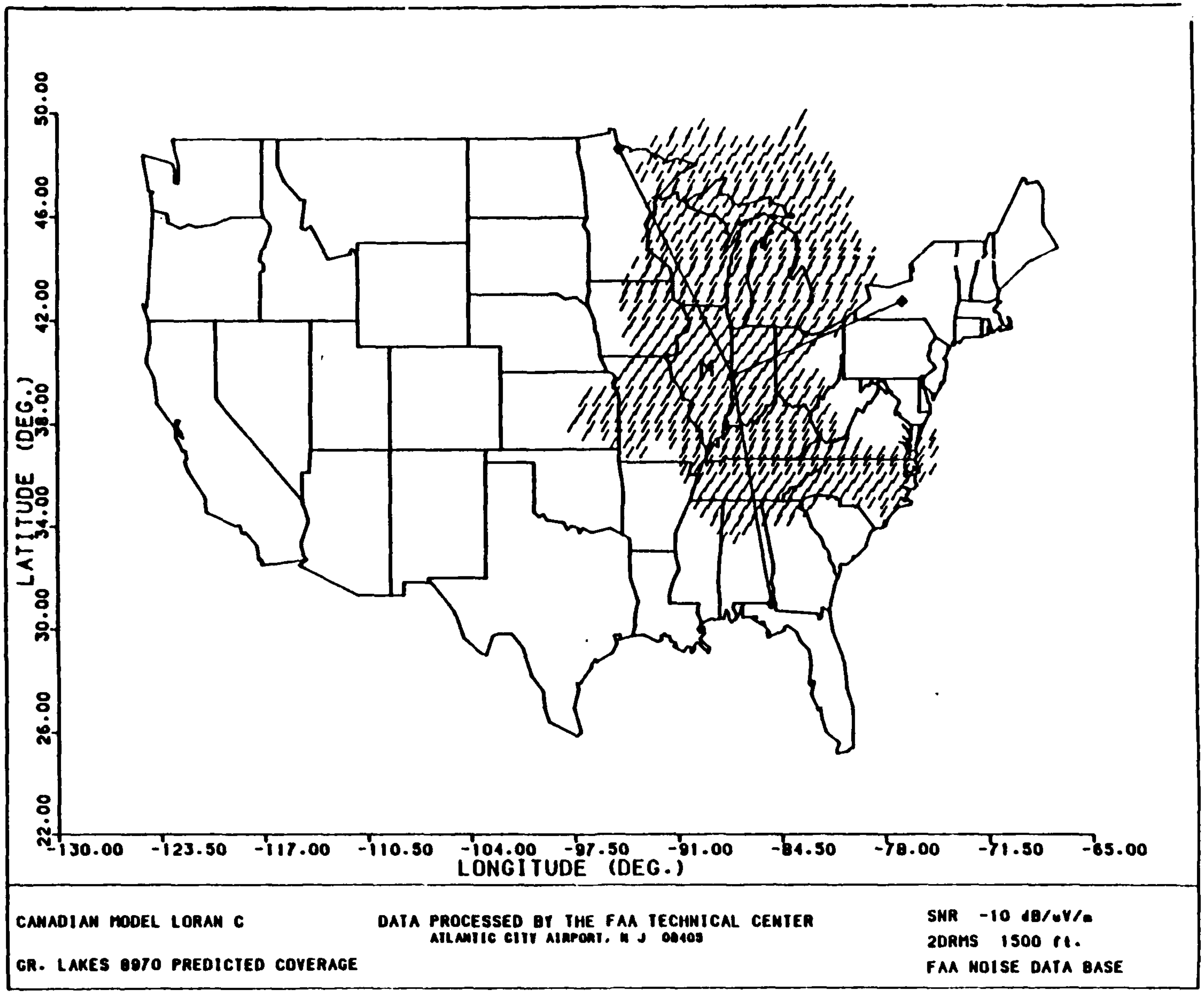


FIGURE E-5. PREDICTED LORAN C COVERAGE FOR THE 8970 CHAIN (FAA REVISED DATA BASES)

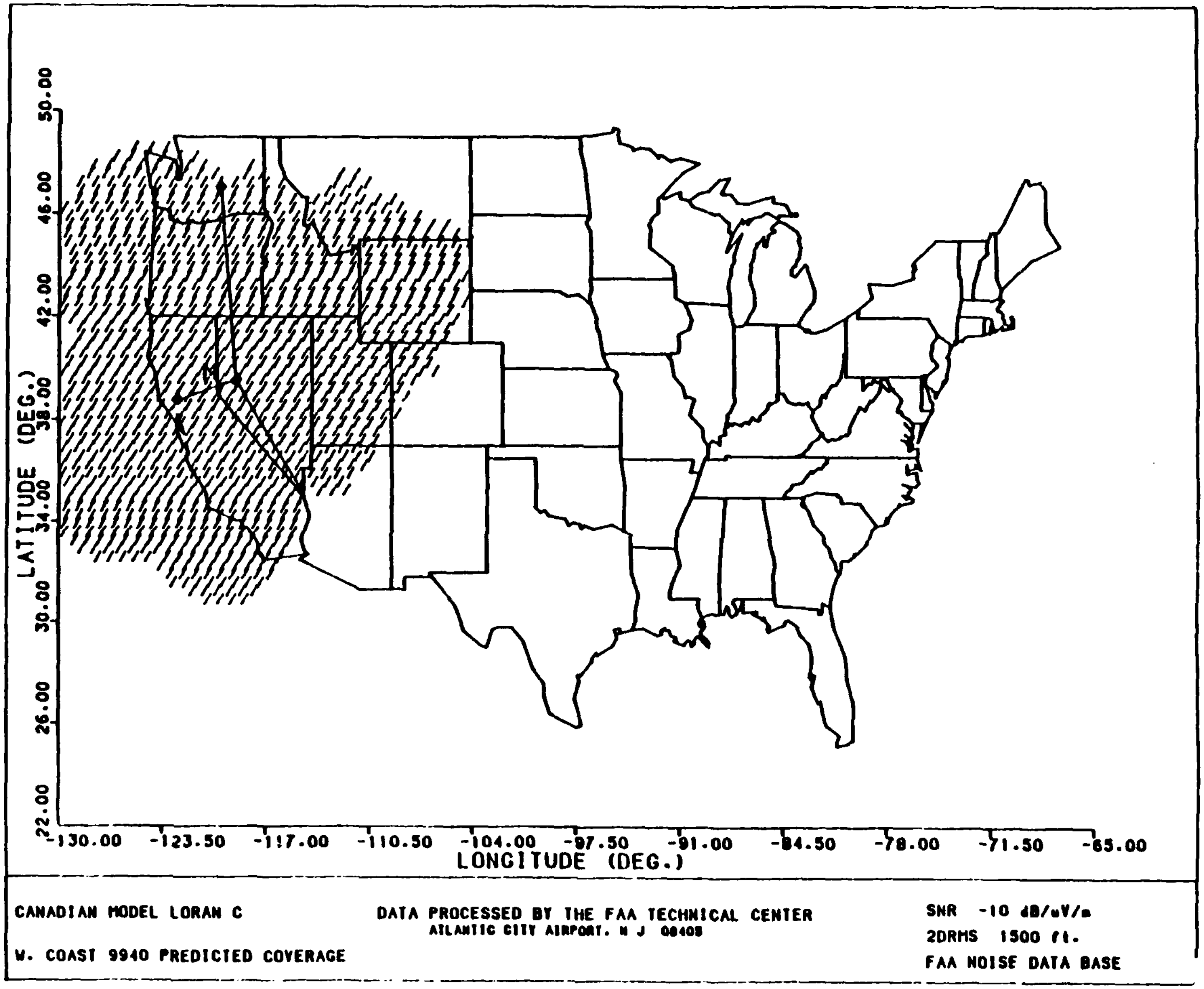


FIGURE E-6. PREDICTED LORAN C COVERAGE FOR THE 9940 CHAIN (FAA REVISED DATA BASES)

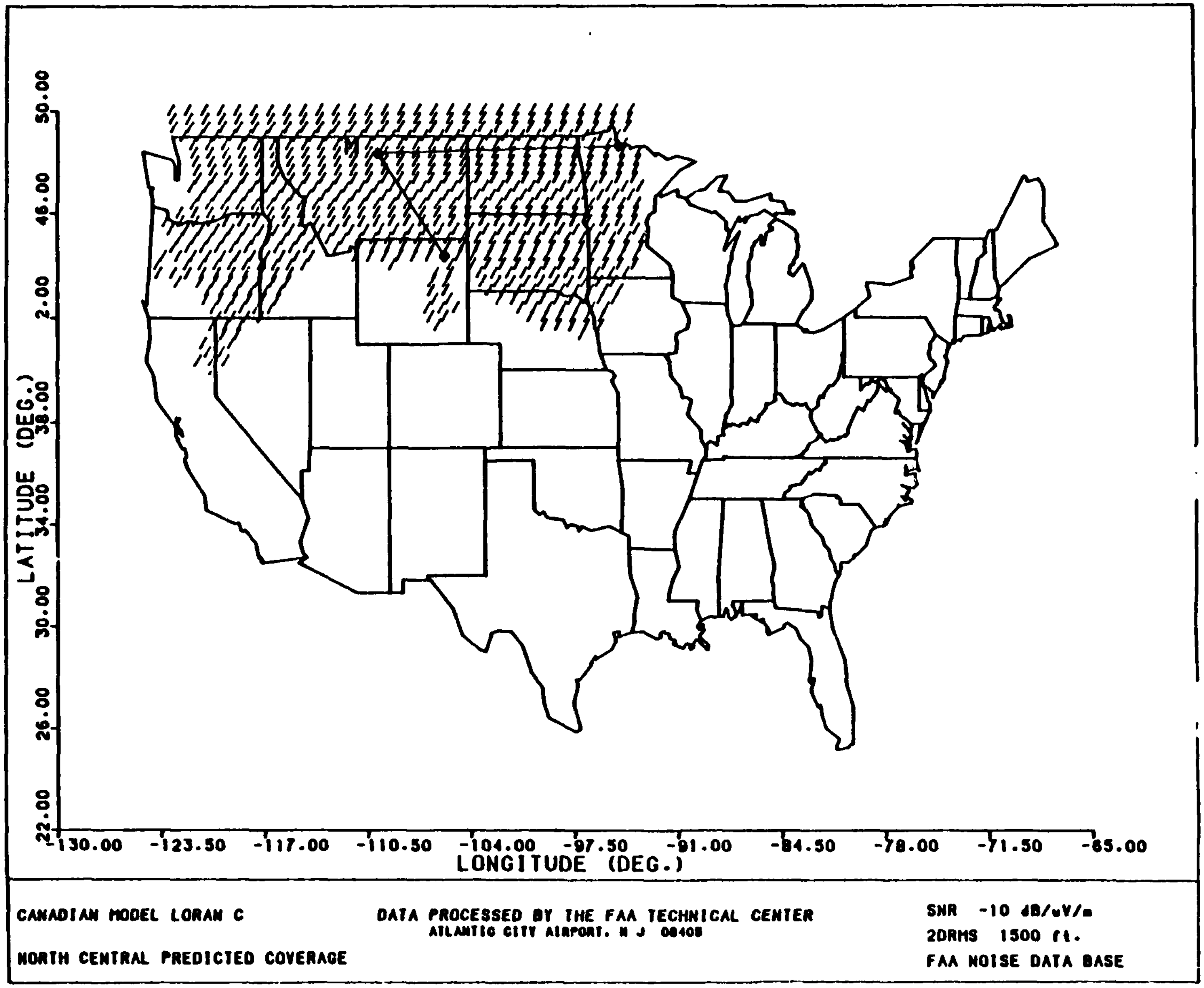


FIGURE E-7. PREDICTED LORAN C COVERAGE FOR THE NORTH CENTRAL CHAIN (FAA REVISED DATA BASES)

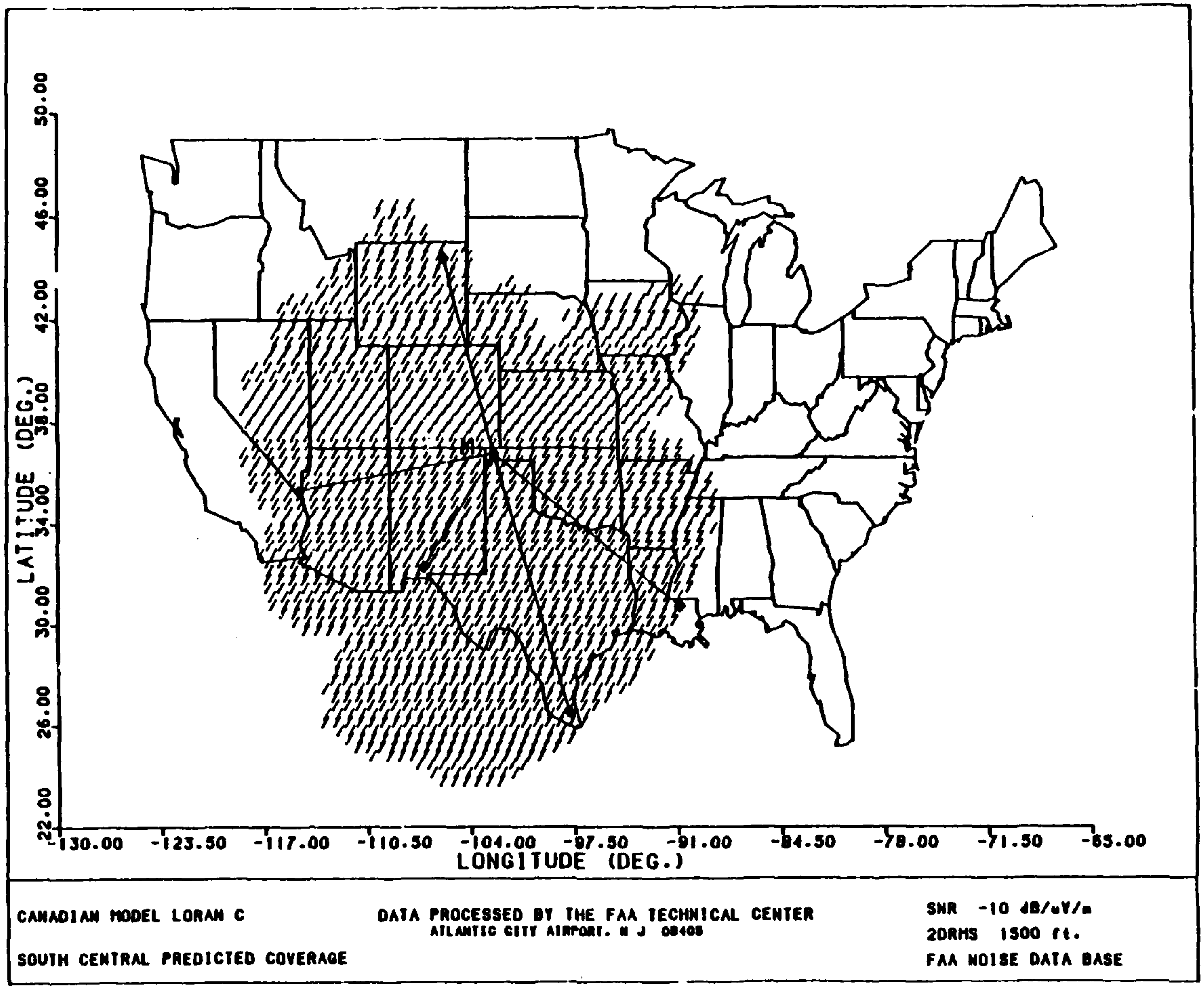


FIGURE E-8. PREDICTED LORAN C COVERAGE FOR THE SOUTH CENTRAL CHAIN (FAA REVISED DATA BASES)

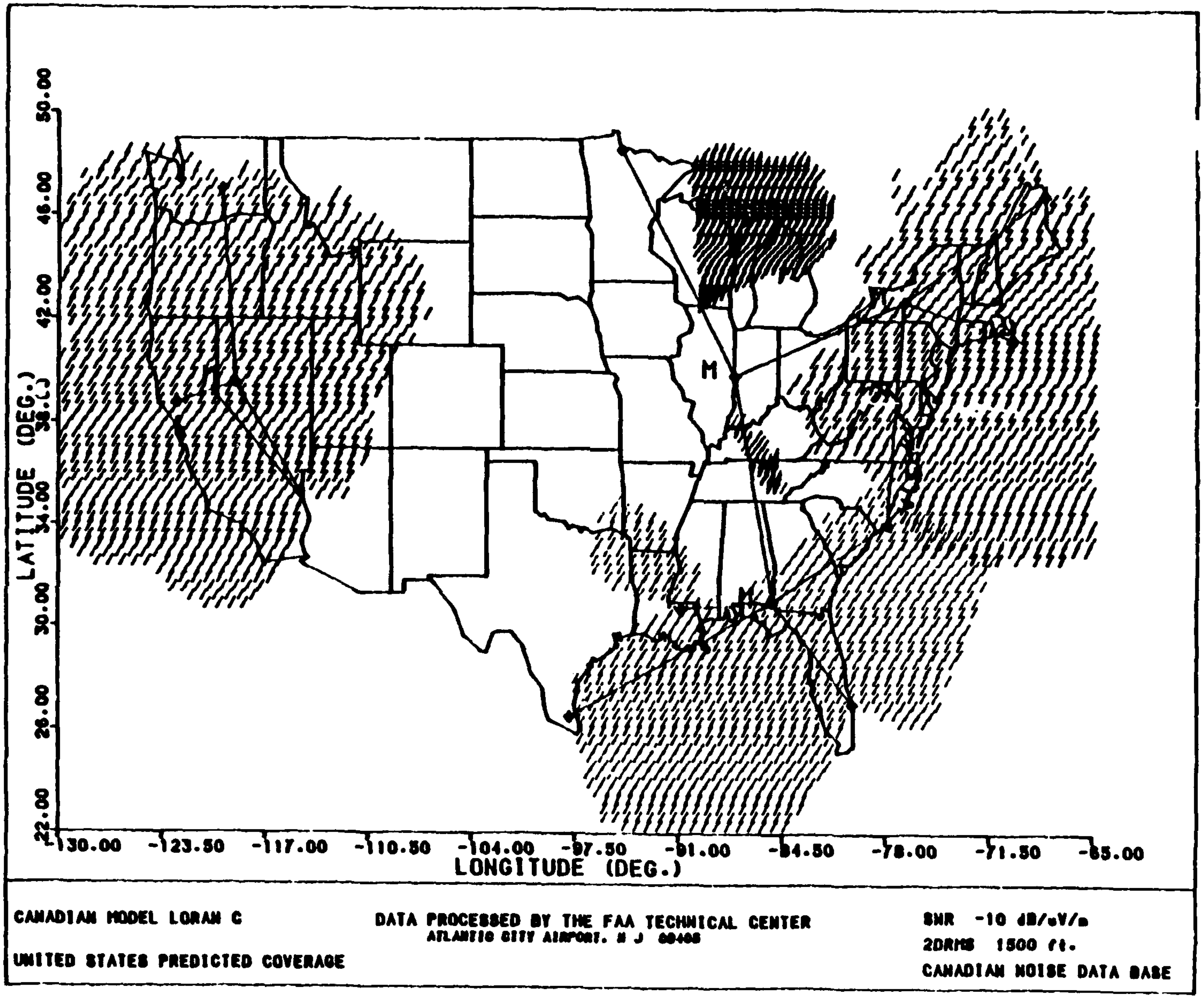


FIGURE E-9. PREDICTED U.S. LORAN C COVERAGE (ORIGINAL CANADIAN DATA BASES)

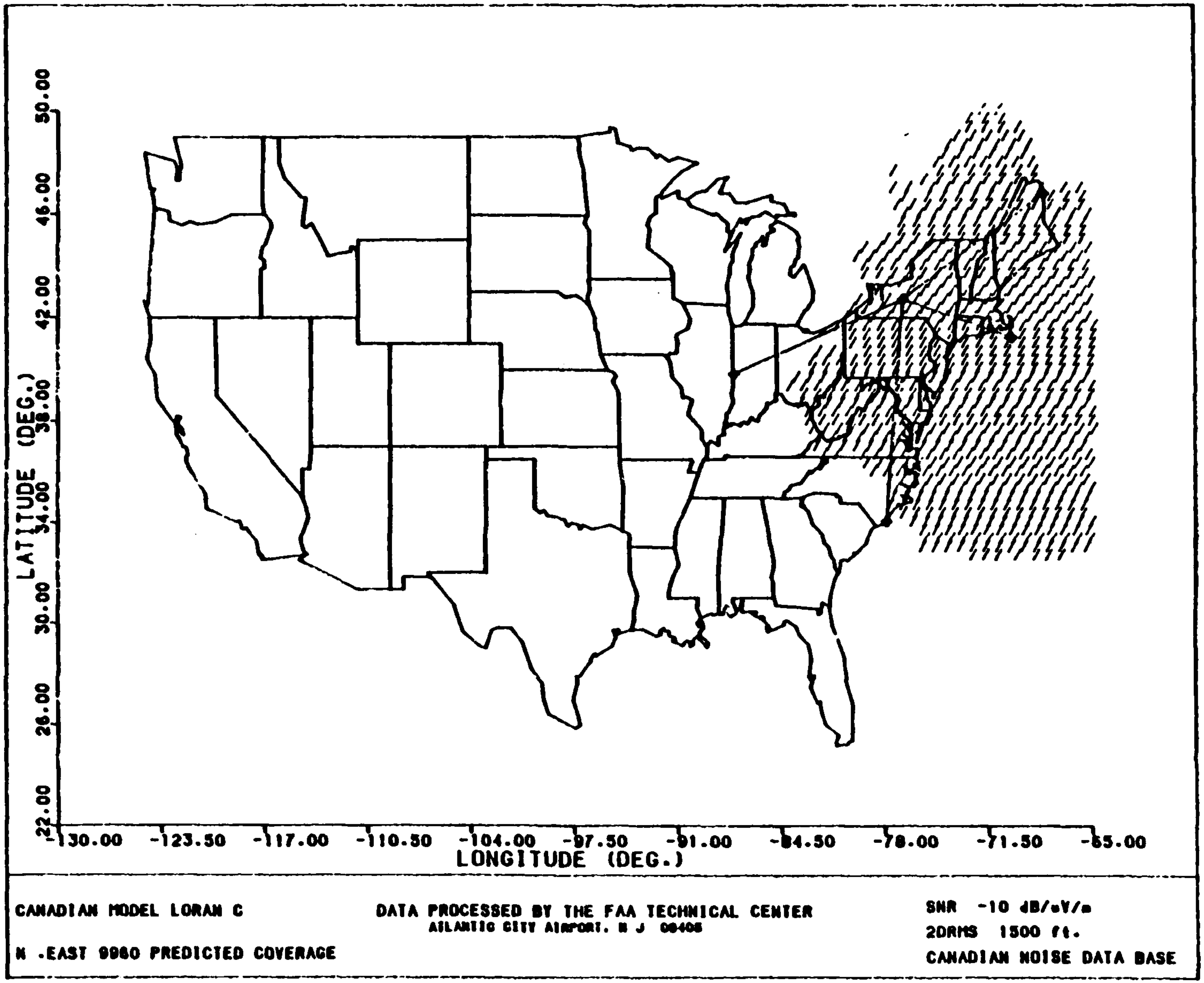


FIGURE E-10. PREDICTED LORAN C COVERAGE FOR THE 9960 CHAIN (ORIGINAL CANADIAN DATA BASES)

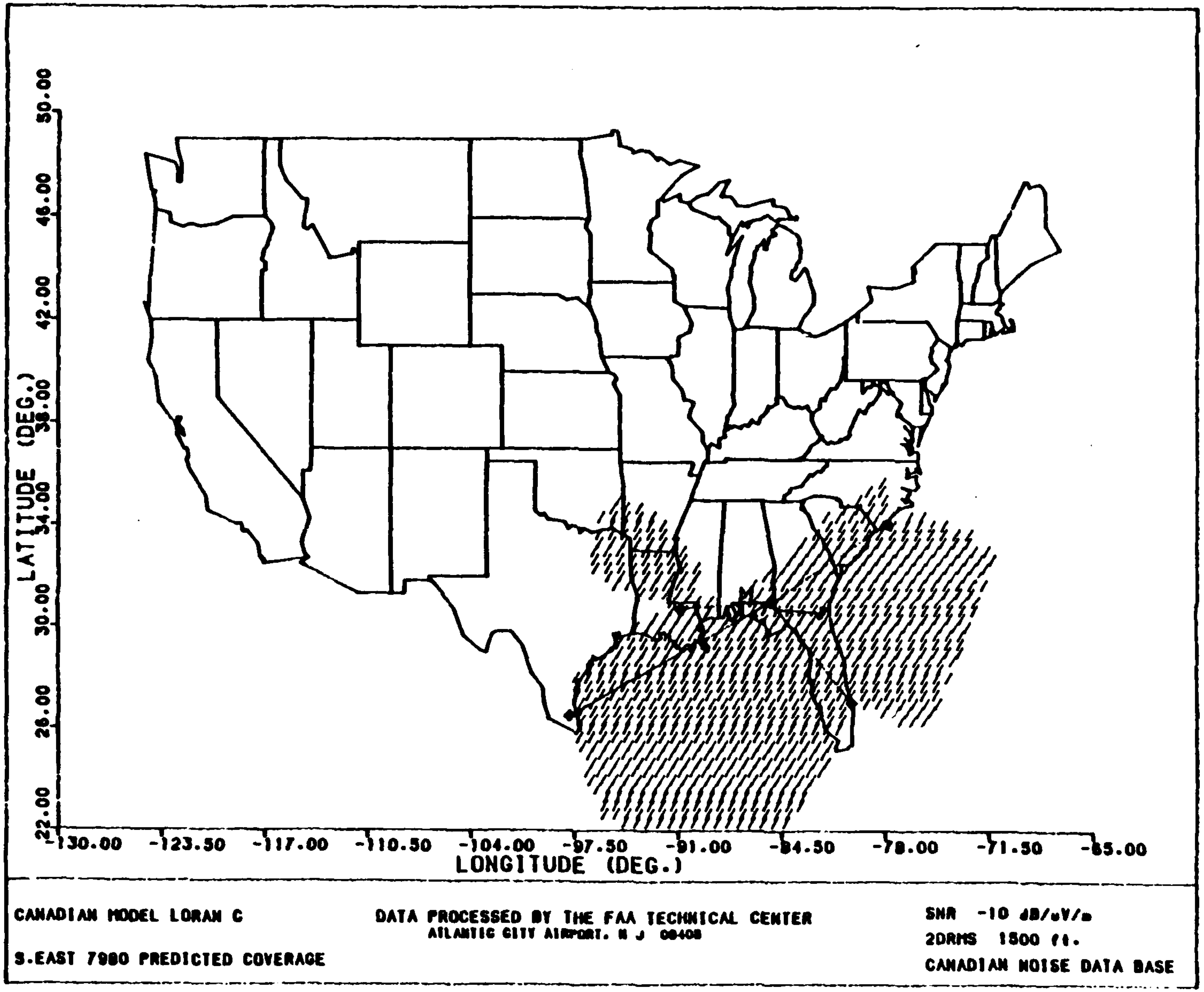


FIGURE E-11. *PREDICTED LORAN C COVERAGE* FOR THE 7980 CHAIN (ORIGINAL CANADIAN DATA BASES)

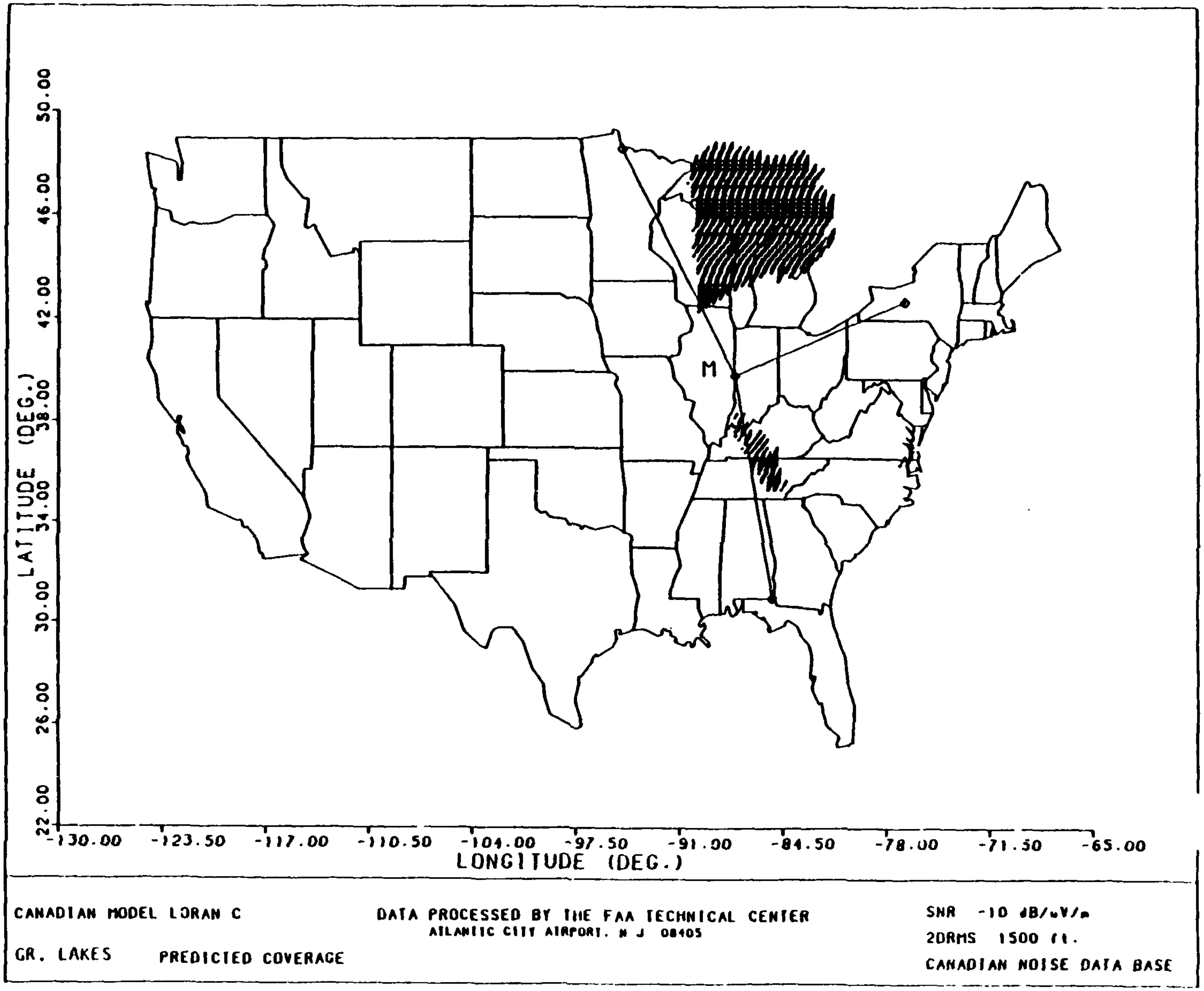


FIGURE E-12. PREDICTED LORAN C COVERAGE FOR THE 8970 CHAIN (ORIGINAL CANADIAN DATA BASES)

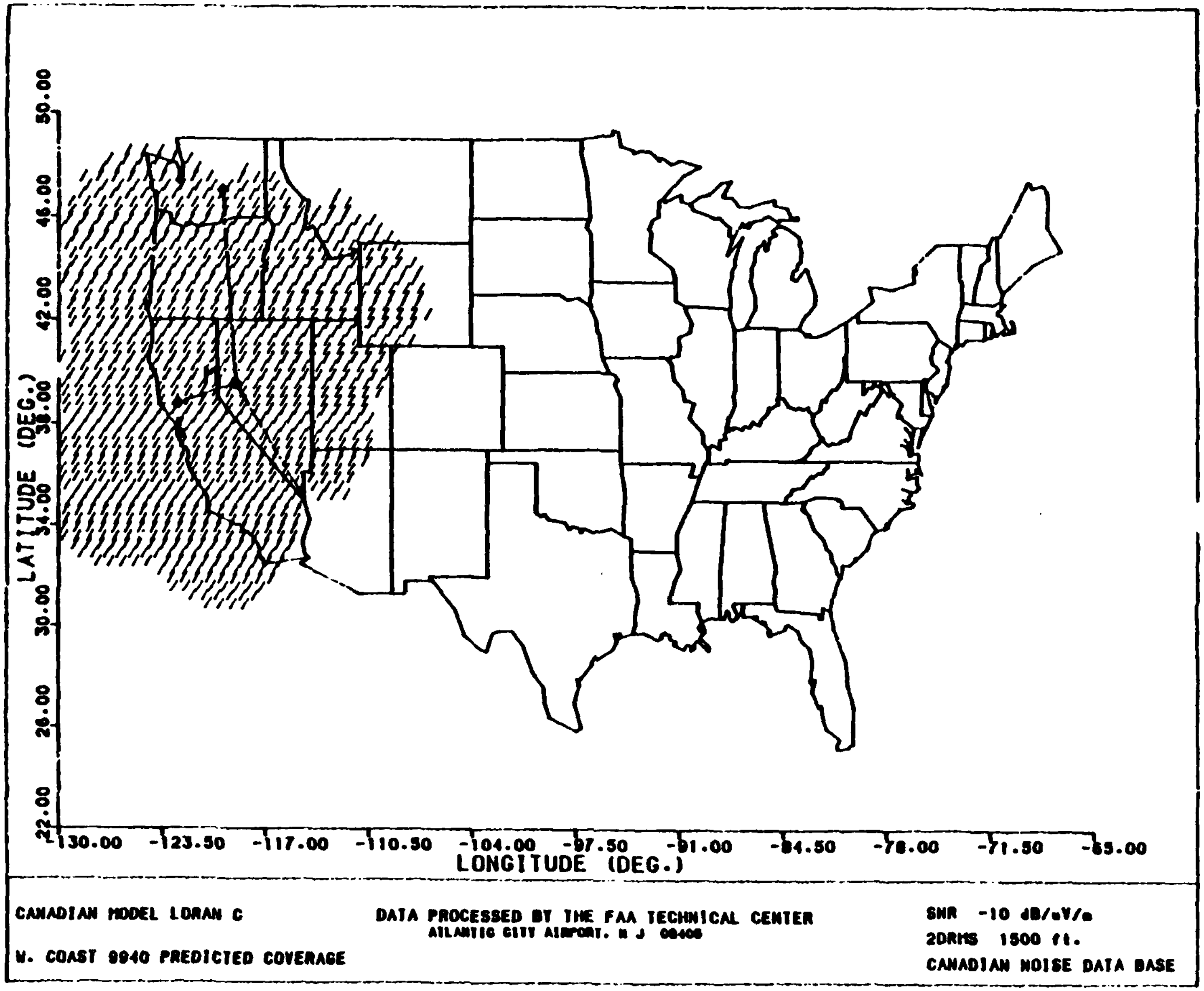


FIGURE E-13. PREDICTED LORAN C COVERAGE FOR THE 9940 CHAIN (ORIGINAL CANADIAN DATA BASES)

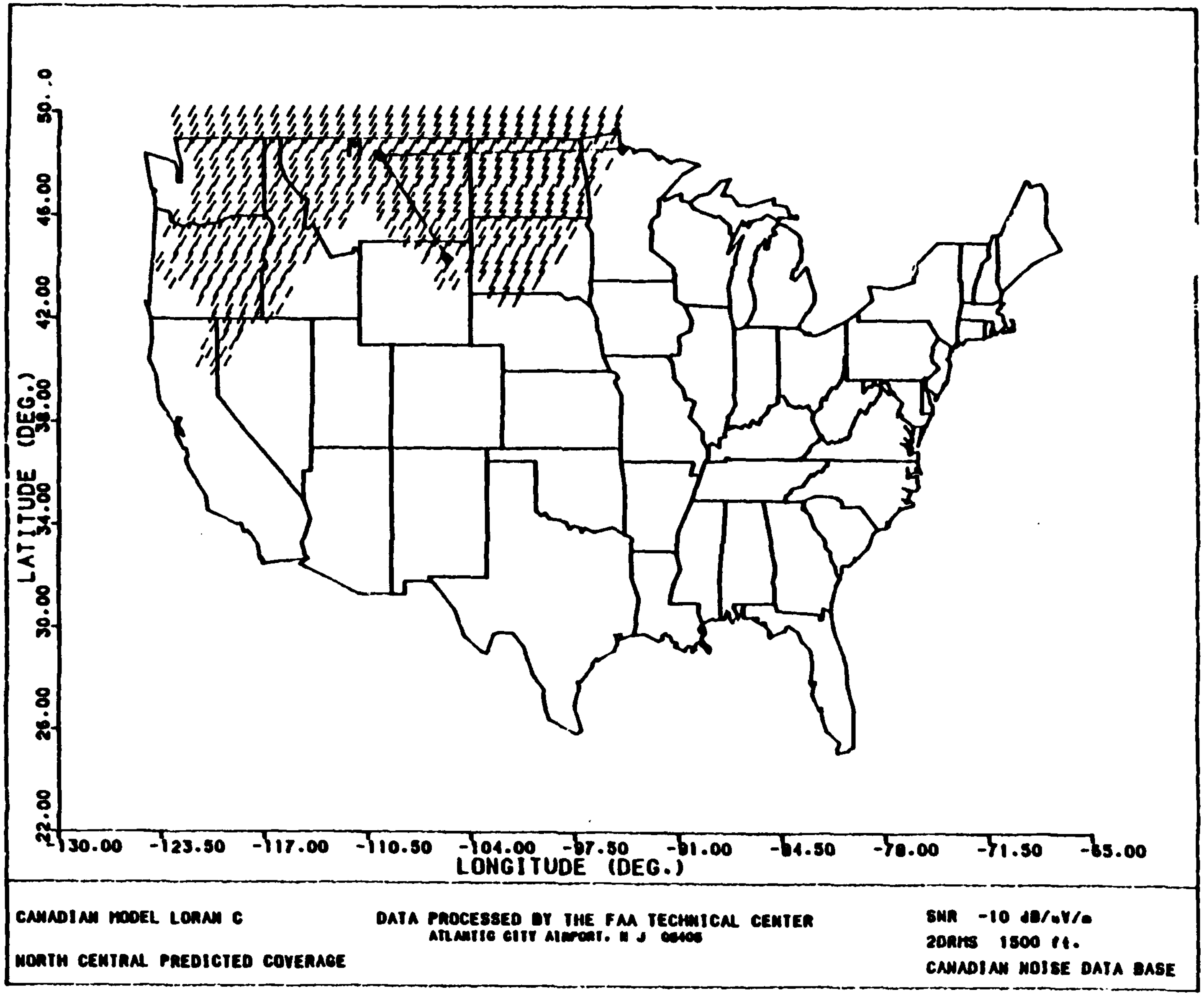


FIGURE E-14. PREDICTED LORAN C COVERAGE FOR THE NORTH CENTRAL CHAIN (ORIGINAL CANADIAN DATA BASES)

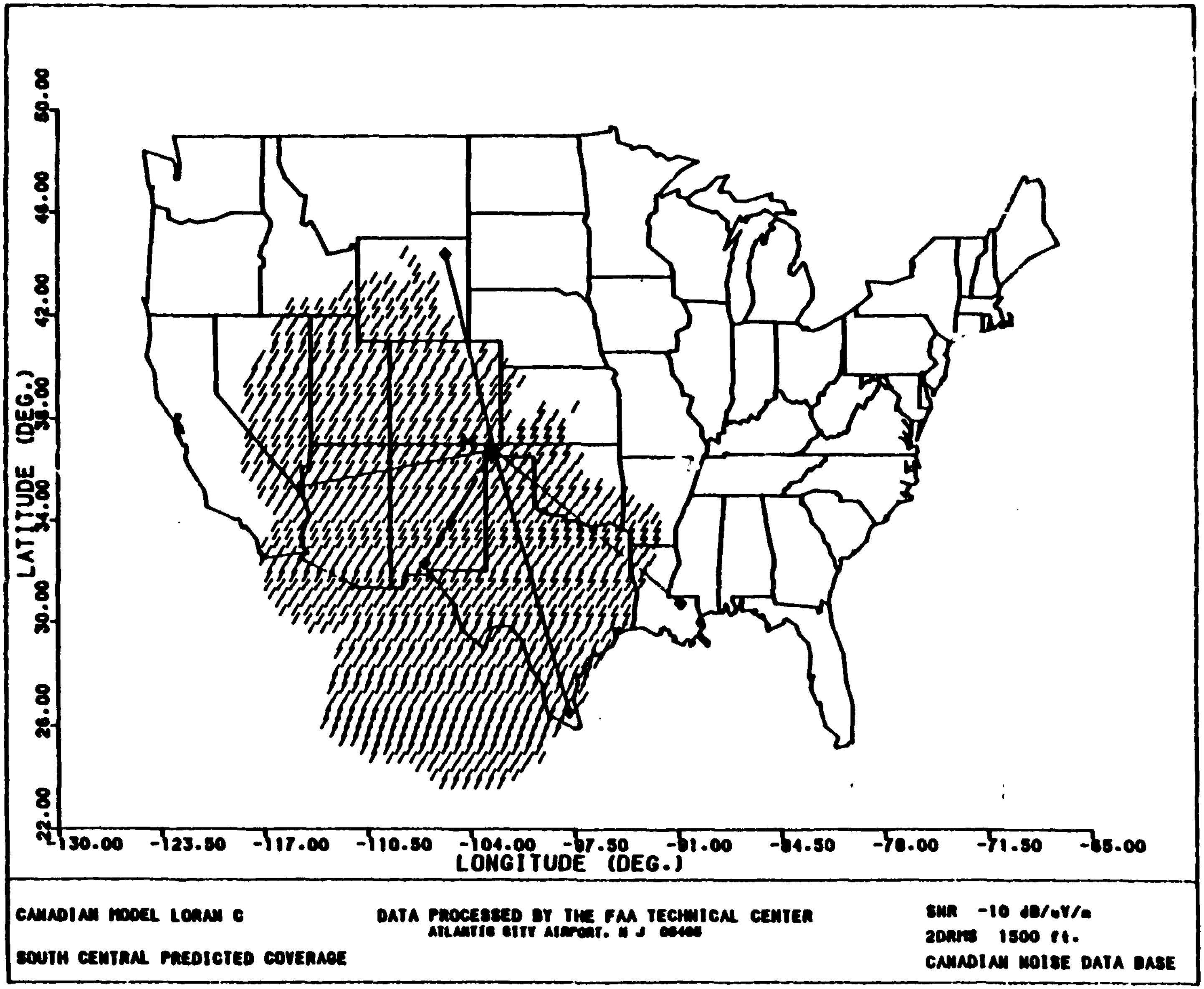


FIGURE E-15. PREDICTED LORAN C COVERAGE FOR THE SOUTH CENTRAL CHAIN (ORIGINAL CANADIAN DATA BASES)